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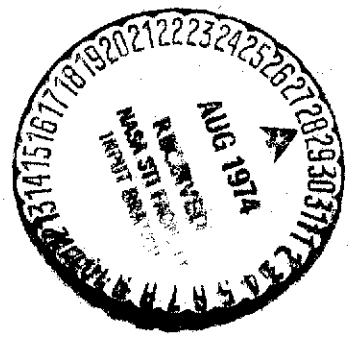

THE AIRCRAFT AND NATURAL CLIMATE CONDITIONS

by K. M. Shpilev and A. B. Kruglov

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16. Abstract

The book examines the influence of natural climatic conditions on the technical state and operation of modern aircraft; it analyzes the primary climatic and soil factors which damage aircraft materiel and their distribution in terms of the Earth's geographical zones. The authors, using materials from the Soviet and foreign public press, show the operational features of an aircraft airframe, engine and of electronic, radio and instrumentation equipment in zones of different climatic conditions and the operational features of airfields, ground service facilities and the work of personnel, and analyze the structural and equipment features of aircraft intended for use in difficult climatic conditions. A number of recommendations by foreign specialists are cited in conclusion with regard to designing aircraft materiel and testing it in conditions imitating the damaging influence of climatic factors.

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FOREWORD

Soviet-made aircraft and helicopters are finding increasingly widespread use in the Motherland, as well as abroad. They are used in the most different climatic conditions and perform varied functions.

In view of this, additional difficulties associated with the necessity to ensure the reliable operation of aircraft materiel when it is based in different regions of the Earth confront specialists designing, manufacturing and operating aircraft materiel. These difficulties are the result of each region's specific environmental effects damaging to aircraft materiel, which are linked with climatic factors. Climatic conditions lead in some cases to a substantial increase in the servicing effort, increased material and labor expenses for the repair and operation of aircraft material, and a reduction in aircraft and helicopter flight performance.

Experience has shown that an aircraft with sufficiently good flight and operating performance under Central European climatic conditions is not always suitable for use in other climatic zones.

It must be acknowledged that aviation specialists on the whole find ways to surmount these difficulties, but their experience, often obtained at a high price, is insufficiently generalized and distributed, and successful design and technological solutions and operational methods do not become available to the wide range of people associated with the development and use of aircraft materiel. Operators do not always have the opportunity to use the articles and statements on these themes found in various publications. The book The Aircraft and Natural-Climatic Conditions deserves special attention in this respect. The authors, after examining the operational features of aviation materiel in different climatic conditions, discuss in an easily understood manner the primary damaging factors and their effect on the structure and equipment of aviation materiel when it is in use.

The authors were able to show how climatic factors affect already operable materiel, as well as how important it is to take into account opportunely, while still in the course of designing, the influence of external conditions on different aircraft elements, and how important it is to create a testing system which will ensure checking for the environment's damaging effects on them.

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The book gives concrete recommendations, which should be used by designers and technicians when building aircraft and helicopters, as well as by operating personnel when servicing them in conformity with the transpolar, tropical and desert-steppe natural zones.

It undoubtedly will be of use to specialists of different trends to read this book.

M. N. Mishuk,
Doctor of Technical Sciences

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INTRODUCTION

The widespread use of aviation placed a crucial task before aviation specialists: to achieve the reliable operation of aviation materiel when it is used in different regions of the Earth. Serious difficulties in accomplishing this task came to light during World War II, when the specialists of a number of countries encountered factors which reduced the effective use of aviation materiel: Fascist Germany - during combat operations under winter conditions; Great Britain - during combat operations in the North African deserts; the U.S. - during combat operations in the tropics of the southern part of the Pacific theater of military operations. The complication of aviation materiel makes the problem of ensuring its reliability under different climatic conditions still more important, and the enormous growth in the importance of aviation makes it urgent to solve this problem. /5*

Experience shows that modern Soviet aircraft operate successfully under the severe conditions of the transpolar region and Antarctica, in the hot and desert regions of Asia and Africa, and in the tropical zones of the Pacific and Atlantic Oceans. At the same time, there are important features in operating aviation materiel in climatic conditions differing from the Central European ones, as well as in basing it on unpaved airfields. The service lives of aircraft and helicopters must be reduced, and material and labor expenses for their repair and servicing increased, in order to use their performance capabilities fully and to ensure the given reliability values.

Extension of the geographical regions where aviation is used and the increase in the number of aircraft and helicopters used in difficult climatic conditions and on unimproved airfields, with the continual complication of aviation materiel, require special approaches to developing designs for such aircraft and helicopters. Attention also must be given here to developing optimum methods for their operation in flight and on the ground. /6

Extremely serious attention has been devoted for a long time in industrial and housing construction, as well as in machine building, to considering the special features of the regions where units will be located or used. The principles of a new science, the study of winter, are being created at present. The machine-building industry; for example, the motor and tractor industry, has

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* Numbers in the margin indicate pagination in the foreign text.

been putting out special-purpose goods in polar and tropical versions for quite a long time. They take into account the features of the climatic conditions of the regions in which these goods are to be used. Unfortunately, this method is still used insufficientely in aviation at present. Therefore, the use of aviation materiel in practice often has to be limited by the adaptation of standard aviation materiel to non-standard conditions.

The development of requirements for the design of special versions of aircraft and helicopters in conformity with the conditions of their operation also is an important question. A considerable part of these requirements can be fulfilled by revising and modifying existing types of aircraft and helicopters which are being used successfully in different conditions. At the same time, these requirements can and must be considered to a much greater degree in the earliest stages of designing new aircraft and helicopters, as well as special types of aircraft and helicopters.

A number of materials usually used in aircraft manufacturing are not completely suitable for use in tropical or transpolar conditions. The timely and technically well-reasoned presentation of requirements for these materials will permit creating and having a given quantity of the necessary materials on time.

When using aircraft and helicopters in different geographical regions, it is necessary to have a clear idea of how their flight performance, servicing effort, and rates of consumption of materials and spare parts change.

Chapter 1

Primary Factors Complicating the Operation of Aviation Materiel

/7

The goal of the operation of aviation materiel is its effective use for the purpose for which intended, upkeep in good working order and constant readiness for use, ensuring reliable operation when in use, and ensuring long service life. The solution to a round of tasks such as these is a very complicated and time-consuming business. The continuous action of the environment on aviation materiel throughout its operation period, and when parked, often greatly complicates the realization of these tasks.

The external factors, in some cases, have a decisive influence on servicing effort and quality, reliability, combat readiness, and service life of aviation materiel, as well as on its in-flight operation. These factors become particularly significant when aircraft are parked in the open, when they are used off fields without artificial coverings, and in areas in which climatic conditions are complex.

There are two groups of environmental factors that have an influence on aviation materiel:

(1) factors that change significantly the rate at which processes that usually take a long time to develop in aviation materiel elements, such as destruction, corrosion, rot, and the like, in fact take place;

(2) factors associated with the interaction of the aircraft with the environment in use, such as change in flight and technical characteristics, the appearance of increased dynamic and vibration loads, of increased wear of structural members, and the like.

/8

Included in the primary factors governing the features of the operation of aviation materiel, and which characterize the region in which based, are:

air temperature and humidity;

solar activity and insolation;

atmospheric electricity;

precipitation, type and amount;

ground strength and composition;

dustiness;

salinity of soil and water;

biological factors;

wind.

What can be considered next is how each of these factors influences the reliability, maintainability, basic flight characteristics, and the organization of aircraft and helicopter operations.

Air Temperature and Humidity

The air temperature at ground level can, as we know, vary quite widely. Temperatures from +60° to -85°C have been recorded, but the range from +50° to -70°C is of practical interest because these temperatures are encountered relatively frequently in regions in which aviation materiel are in constant operation. Figure 1 shows the geographic regions with particularly high air temperatures.

Temperature must be considered in conjunction with the absolute (or relative) humidity, from the point of view of how temperature influences flight and technical operations, because humidity often brings about a root change in the action of temperature on materiel, as well as on flight and technical personnel. The most dangerous combinations in this regard are high temperature and high humidity, and low temperature and high humidity.

The combinations of high temperature and high humidity is characteristic of the coastal regions of the tropical and subtropical zones.

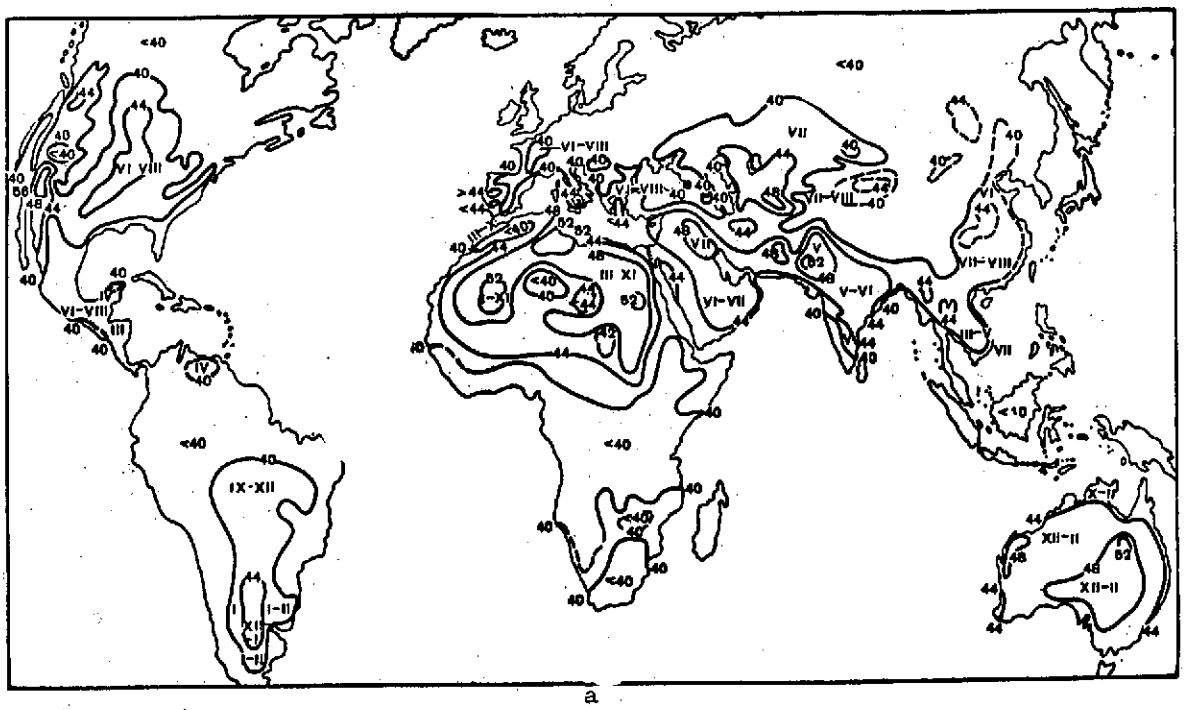
The mechanical properties of many materials depend on how much moisture they contain, and this, in turn is the result of the interaction between temperature and humidity of the ambient air. Air temperature changes with change in moisture in the atmosphere. This takes place as a result of the scattering and /9
reflection of solar rays by tiny droplets of water suspended in the air in the form of fog, clouds, mist, as well as the result of the processes of absorption of waves of certain lengths by water vapor, evaporation, and condensation (rain, dew).

The so-called damage index, A, is used abroad to characterize the combined effect of humidity and temperature on materiel

$$A = b\frac{H-\kappa}{100}\cdot 1{,}054^{t}, \qquad (1.1)$$

where

b and k are coefficients obtained experimentally (for the tropics b = 1, k = 65);



a

b

Figure 1. Absolute maximum air temperature (above 40°C) on continents (a) and number of days per year with temperature above 40°C (b).

H is the air's relative humidity;

t° is temperature, °C.

The higher the value of A, the greater the damaging effect of climatic conditions on aviation materiel.

The following characteristic malfunctions may occur as a result of the combined effect of high temperatures and humidity:

seizing of the precision couples due to unequal thermal expansion of their elements, made of different materials;

upsetting of the radio engineering devices because of change in the parameters of their elements;

dilution and leakage of lubricants;

reduction in viscosity and loss of lubricating properties by the hydraulic system working fluid;

deterioration of the physical and mechanical characteristics of the sealants, insulation, plastics, glazing, etc.;

abrupt activation of corrosion processes on metal surfaces;

occurrence of off-design thermal conditions of systems and devices due to lack of power of the cooling systems;

cracking, loss of elasticity and lag from the skin of the paint-and-varnish coating in large areas;

failure of the rubber shock absorbers and covers, and premature failure of the tires and braking units; /12

self-discharge and breakdown in the normal operation of the electrical batteries because of loss of the active substance of the plates.

A negative result of the effect of high temperatures is the considerable loss of flight and technical characteristics by aircraft and helicopters. Engine thrust decreases with increase in ambient air temperature. Thus, a change in air temperature from -30 to +30°C leads to a decrease in engine thrust in the maximum regime of up to 40-45%. This is caused by the fact that when the temperature increases, the air density decreases, and, consequently, the amount of oxygen per unit volume of air participating in the fuel combustion process (air density decreases by approximately 2% with increase in air temperature by 5°C from standard, and the weight of oxygen per unit volume of air decreases accordingly).

The take-off run and take-off distance increase, aircraft rate of climb decreases, and fuel consumption increases because of a decrease in engine thrust.

It is known that the relationship between the take-off run and outside air temperature for aircraft with turbojet engines is defined as

$$L_t = L_{t_0} \frac{p_0}{T_0} \cdot \frac{T}{p} \cdot \frac{\frac{1-f_f}{\mu_0}}{\frac{p}{p_0}\left(\frac{T_0}{T}\right)^m - \frac{f_f}{\mu_0}}, \qquad (1.2)$$

where

L_t is the take-off run with change in the outside air parameters (of temperature and pressure) [m];

L_{t_0} is the initial take-off run (reduced to standard conditions) [m];

p_0 is the standard atmospheric pressure [mm Hg];

p is the actual atmospheric pressure [mm Hg];

T_0 is the standard air temperature [K];

T is the actual air temperature [K];

f_f is the friction factor of the wheels against the runway;

μ_0 is the average thrust-to-weight ratio of the aircraft in standard conditions [kgf thrust/kgf weight]; /13

m is the exponent (determined experimentally).

This formula also takes into account the effect on the take-off run of the height above sea level of the airfield. An analysis of it, as well as experimental research, shows that change in temperature has a very significant effect on the take-off run (Figure 2). The landing run changes similarly (Figure 3).

Air humidity also affects engine thrust. This occurs because of the displacement by water vapor of the dry air together with the oxygen contained in it. Consequently, the amount of oxygen per unit volume of air passing through the engine decreases, less oxygen takes part in the combustion process per unit of /14 time, and this reduces engine thrust. The water contained in the air in the form of rain drops or particles of fog does not reduce engine thrust. Rain, even a heavy shower, does not cause failure in engine operation.

The result of a reduction engine thrust at high air temperatures is a decrease in maximum flight speed. This is especially applicable to supersonic aircraft.

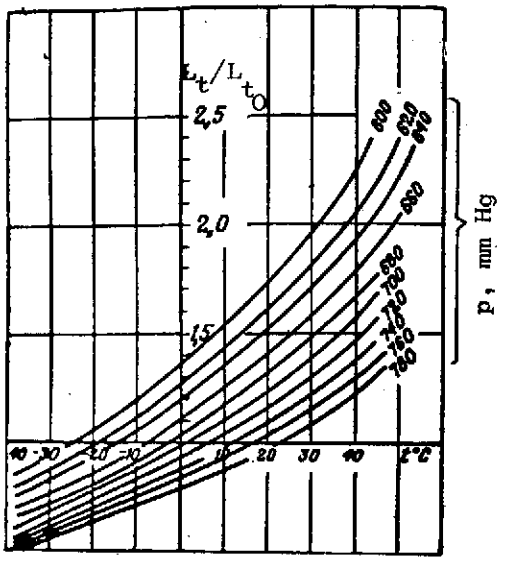


Figure 2. Relative change in the take-off run of an aircraft with change in outside air temperature and pressure: L_{t_0} is the take-off run under standard conditions, L_t is the take-off run under actual conditions.

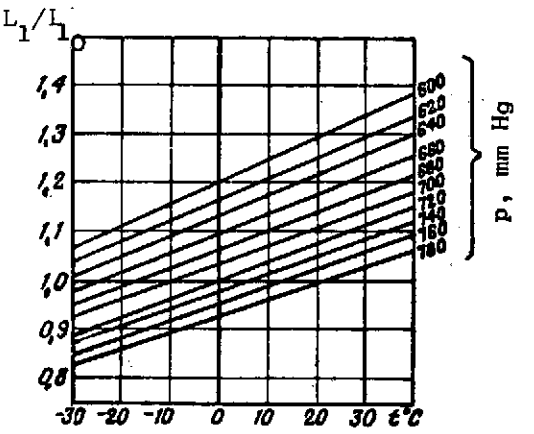


Figure 3. Relative change in the landing run of an aircraft with change in outside air temperature and pressure: L_{1_0} is the landing run under standard conditions, L_1 is the landing run under actual conditions.

The decrease in maximum speed for aircraft with turbojet engines is estimated as follows:

$$\Delta V = V_{\max_0}\left[\frac{\Delta M}{M}\left(1-\frac{1}{2}\cdot\frac{\delta T}{T_0}\right)-\frac{1}{9}\cdot\frac{\delta T}{T_0}\right], \qquad (1.3)$$

where

$V_{\max_0}$ is the maximum speed under standard conditions [km/h];

ΔM is the change in the Mach number with increase in temperature;

T_0 is the standard absolute air temperature [K];

δT is the change in ambient air temperature.

The decrease in flight speed may be considerable; therefore, the change in atmospheric conditions should be taken into consideration when drawing up the flight mission. /15

The rate of climb decreases still more considerably with increase in temperature. Thus, the climb time to 10,000 m at an air temperature of 35-40°C increases for some types of aircraft by 12-15 minutes in comparison with standard conditions. Figure 4 shows the change in maximum vertical velocity in relation to temperature.

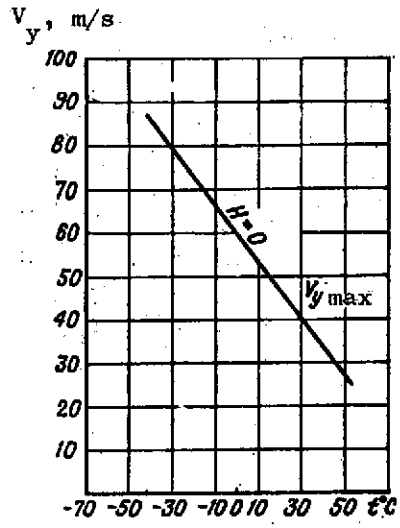


Figure 4. Change in maximum vertical velocity in relation to ambient air temperature.

Technical flight range and duration decrease with increase in ambient air temperature. This occurs because with heating, firstly, fuel density decreases and, consequently, the aircraft fuel capacity by weight, and secondly, hourly fuel consumption increases.

The decrease in flight range and duration due to the decrease in density of the fuel loaded into the aircraft's tanks can be calculated by the formulas:

$$\Delta L_{hf} = \frac{W\left(1-\frac{\gamma}{\gamma_0}\right)}{q} \text{ [km]}; \quad (1.4)$$

$$\Delta T_{hf} = \frac{W\left(1-\frac{\gamma}{\gamma_0}\right)}{G_h} \text{ [h]}, \quad (1.5)$$

where

W is the total capacity of the aircraft's fuel system [l];

γ is the fuel density at the actual temperature [g/cm^3];

γ_0 is the fuel density at standard temperature [g/cm^3];

q is the fuel consumption per kilometer for the particular mode [l/km];

G_h is the hourly fuel consumption for the particular mode [l/h].

Consumptions per kilometer and, consequently, flight range do not change when flying at a given altitude with a constant indicated airspeed when a change in air temperature occurs, and hourly consumptions and engine speed depend on it.

The relation between the change in the relative hourly fuel consumption and the revolutions of the engine rotor and in the relative change in temperature may be determined by the formulas:

$$\frac{\delta G_h}{G_h} = 0{,}5 \cdot \frac{\delta T}{T}; \quad (1.6)$$

$$\frac{\delta n}{n} = 0{,}5 \cdot \frac{\delta T}{T}. \quad (1.7)$$

Thus, the hourly fuel consumption and the revolutions of the engine rotor change with change in temperature by approximately 1% for each 5°C.

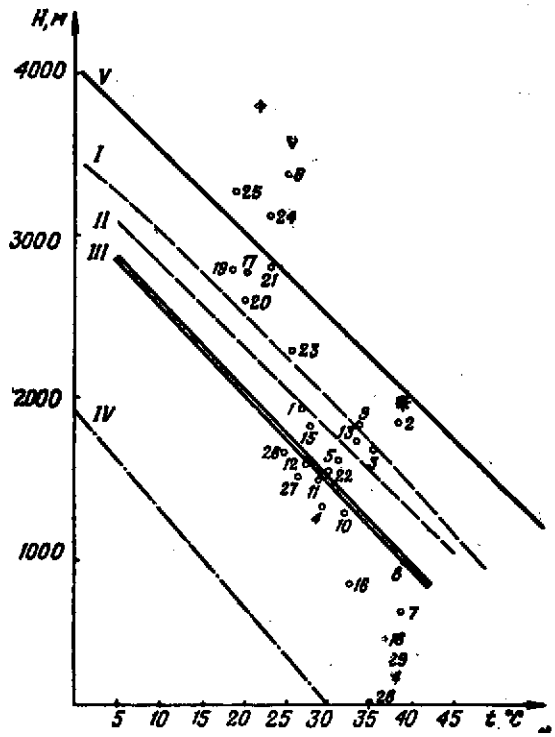


Figure 5. Influence of air temperature and height of terrain (pressure) above sea level on the hovering characteristics of helicopters:

+, *, ▽, O are points in different regions of the Earth. [+ is the U.S.S.R. (Murgab); ▽ is the U.S.S.R. (Kara-Kul'); * is the U.S.S.R. (Khorog); 1 is Turkey (Erzurum); 2 is Iran (Kerman); 3 is Pakistan (Quetta); 4 is Nepal (Katmandu); 5 is India (Srinagar); 6 is India (Lekh); 7 is Iraq (Rutba); 8 is Saudi Arabia (Khilla); 9 is Afganistan (Kabul); 10 is the Republic of South Africa (Kroonstad); 11 is Southern Rhodesia (Salisbury); 12 is Zambia (Solwezi); 13 is Morocco (Midelt); 14 is the Congo (Kinshasa); 15 is the Congo (Nyoka); 16 is Argentina (Mendosa); 17 is Bolivia (Sucre); 18 is Brazil (Ibipetuba); 19 is Chile (Petrepilios); 20 is Columbia (Bogota); 21 is Ecuador (Quito); 22 is Guatemala (Guatemala); 23 is Mexico (Mexico); 24 is Peru (Cuzco); 25 is Peru (Jauta); 26 is Venezuela (Merida); 27 is South Viet Nam (Dalat); 28 is South Viet Nam (Saigon); 29 is Laos (Luang Prabang); 30 is the Democratic Republic of Viet Nam (Lang-Son); I-V is the relationship between the height at which hovering is possible (vertical take-off and landing) and temperature for helicopters designed according to tactical and technical specifications: I is 1830 m/35° (U.S.A., new); II is 1830 m/30° (France); III is 1830 m/25.6° (Great Britain); IV is 1830 m/3.3° (U.S.A., old): V is 2000 m/40° (U.S.A., future)].

However, an increase in temperature and a decrease in atmospheric pressure have the greatest effect on the hovering characteristics of a helicopter. Figure 5 shows how quickly the maximum height at which helicopters may hover decreases with increase in air temperature and height of terrain (pressure) above sea level. This figure shows the averaged maximum daily temperatures of the warmest

month and the height above sea level of 33 points on the Earth, according to many years of observations. The figure shows that the hovering characteristics of some types of helicopters cannot ensure their normal operation in the high mountain regions with a hot climate characteristic of Central Asia, the Near East and the Latin American countries. Since high temperatures occur in the light portion of the day, most suitable for flights, helicopters are unable /18 to realize their main advantage, vertical take-off and landing with the design payload, in these regions for a considerable part of the year. We may cite the following an an example: the SN-47A American helicopter is used in South Viet Nam with a payload of 2.9 tons instead of the design load of 4.2 tons because of the low air density and high temperatures and relative humidity. Its cruising speed is reduced from 204 to 175 km/h.

Figure 6 shows how the flight weight of a Mi-1 helicopter, at which vertical /19 take-off and landing at maximum revolutions of the engine shaft is ensured, changes in relation to air temperature and atmospheric pressure, and Figure 7 shows the influence of a change in barometric pressure on the minimum flight speed of the Mi-4 helicopter.

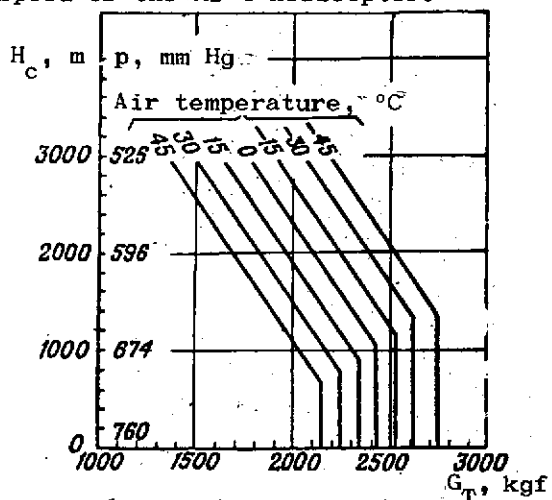


Figure 6. Influence of air temperature and atmospheric pressure on the flight weight of the Mi-1 helicopter, at which vertical take-off and landing at maximum revolutions of the engine shaft is ensured.

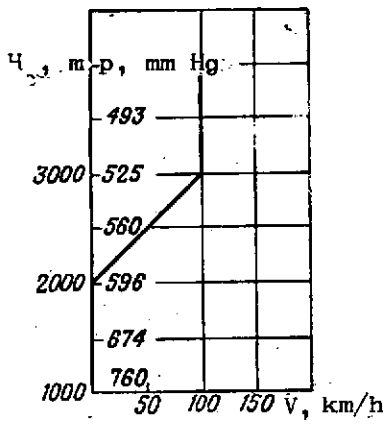


Figure 7. Influence of barometric pressure on minimum flight speed of the Mi-4 helicopter.

An increase in air temperature also impedes engine starting, especially from a turbine starter, the power of which decreases considerably when this occurs.

The combination of low air temperatures and high relative humidity also has an extremely unfavorable effect on the state of aviation materiel in the

operationg process, and can cause:

the approach of engine conditions to the upper surge line (at maximum revolutions);

loss of physical and mechanical characteristics by sealants and insulations (rubber, plastic and others);

difficulty in ignition of the fuses and in destruction of the explosive payload;

drop in initial speed of bullets and projectiles;

reduction in effectiveness of the ejection installations and cartridges;

reduction in the fuel consumption rate;

change in the mechanical properties of metals and alloys;

locking of the valve plunger couples and gear couples due to a difference in the thermal expansion ratios;

thickening of lubricants, fuel and the hydraulic system working fluid;

loss in performance of electric and radio equipment as a result of change in the parameters of a number of important elements;

change in the dielectric properties of insulating materials;

destruction of paint-and-varnish coatings;

icing and frosting over of electric contacts;

freezing of elements of the kinematic systems;

misting of the instrument glasses and aircraft glazing.

Solar Activity and Insolation /20

Magnetic storms, ionospheric disturbances and polar aurorae occur as a result of solar activity. A result of magnetic storms and ionospheric disturbances is the impassability of radio waves, which may completely deprive the aircraft of radio communication at certain moments. Magnetic storms, in addition, have a strong effect on the operation of magnetic compasses, especially at great altitudes, where the Earth's magnetic field is weaker.

Polar aurorae, in flights over regions without light markers, may cause the pilot to have a false idea of the aircraft's position in space.

Insolation, the action of direct solar rays, accelerates the destruction of paint-and-varnish coatings, fabrics and rubber hardware, and the formation of microcracks in rubber and plexiglass articles ("silver" on glazing). The recombination of oxygen atoms with ozone molecules, which accelerates the ageing

processes of rubber hardware and the destruction of paint-and-varnish coatings, occurs under the action of solar rays.

Atmospheric Electricity, Static Electricity

An aircraft (in flight, as well as on the ground) can acquire a considerable electrical charge as a result of the effect on the airstream of hot ionized fuel combustion products; friction against the skin by sand particles, dry snow and the airstream; and friction by the fuel against the walls of the pipeline and the fuel system tanks when the aircraft is fueled. The magnitude of the charge may be quite considerable. A potential difference of from 500,000 to 1,000,000 V may appear in a short time on the surface of a heavy aircraft. Discharges over 1 m in length have been observed in certain cases. Corona discharges, which disrupt radio communication, occur on the sharp edges of an aircraft structure when the potential difference is 40,000-80,000 V. The aircraft electrifies especially intensively if the air is saturated with dry snow, which is characteristic of some parts of the Transpolar region and Asia, as well as when flying in /21 dusty air.

Charges from conducting and semiconducting skins (aerial fairings, non-metallic honeycomb structures and the like) pass into the primary structure and move to the side of sharp edges, from which they flow into the atmosphere. This phenomenon does not cause complications if all aircraft parts are well joined. Corona discharges and sparking occur, however, where there are gaps, sections that do not conduct electrical charges and sharp edges. Fire and explosion in the fuel tanks, internal compartments of the structure and the vent system pipes is not excluded, because the fuel-air mixture in the aircraft is always at a dangerous concentration.

There is always a certain amount of electrodissociating substances in aircraft fuel consumption. The positive and negative charges in the fuel neutralize each other under fixed conditions, particles of the electrodissociating substances with a charge of one sign accumulate on the pipeline walls in the fueling process, and those with an opposite charge go with the fuel into the aircraft's tanks. The magnitude of the currents of such charges does not exceed 10^{-6}A, but a considerable potential difference between the fuel and the tank walls may occur when there is a large quantity of fuel and high rates of fueling, which will cause

an electric discharge. The potential difference increase with increase in the fueling rate, in the volume of fuel loaded and in the degree of filtration (a large active surface of the filter may accelerate the dissociation process by a factor of 10-200, and the type of filter has a slight influence on the intensity of dissociation).

The charges accumulated during fueling flow into the structure faster the less the specific electrical resistance of the fuel, which usually is within the limits of $1 \cdot 10^{14}$ - $1 \cdot 10^{13}$ ohm·cm.

The electric conductivity of the fuel and the safety of fueling may be increased considerably (by a factor of 10-100) by using special additives. They are a compound of metal salts of organic acids and polymers (for example, the ASA-3 additive used in England is introduced in the following quantity: 3 mg to 1 liter of fuel). The time necessary to decrease the charge by half can be calculated approximately from the formula /22

$$t_{1/2} = \frac{12}{\kappa},$$

where k, the electric conductivity of the fuel, is the reciprocal of the specific volume electrical resistance.

Splashing of the fuel during fueling increases the ratio of accumulating charges and, in addition, increases the explosive risk due to the formation of a mist of tiny drops of fuel. It is therefore necessary to take measures to exclude the formation of a free jet during fueling. Closed fueling from below under pressure yields the best result. It also is desirable to use an extended fueling pistol tip.

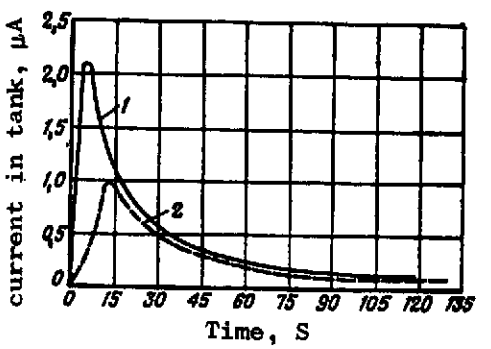


Figure 8. Change in current intensity in a tank during fueling: 1 is a new filter; 2 is a filter after 25 fuelings.

Current intensity may change considerably during fueling, quickly increasing in the beginning of fueling and gradually decreasing, as Figure 8 shows. Figure 9 shows the change in field intensity in the tank when it is being fueled. The rate of increase in field intensity decreases because of the occurrence of a corona discharge at points 1

and 2. The greatest potential danger, therefore, is the accelerated refueling of aircraft tanks, for example before a repeated departure. The charges, concentrating on the decreasing surface of the upper part of the tank, may reach a local value (at the sensors, fuel gauge floats and the like) of up to 3000 kV/m, /23 which is sufficient for sparks to occur. Sparking also may occur at the edge of the fueling pistol in the beginning of fueling as a result of the creation here of a high initial local potential. Such cases occurred even with low (up to 1.10^{12} ohm·cm) specific electrical resistance of the fuel.

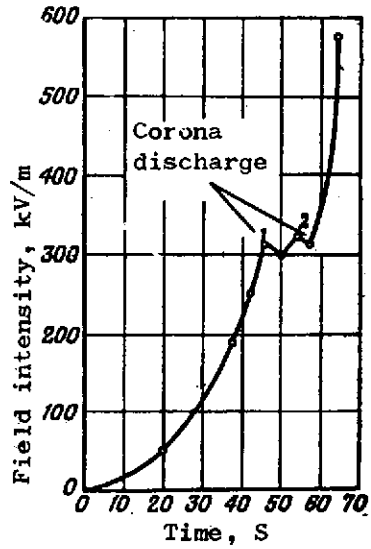


Figure 9. Change in the electric field in a tank when it is being fueled.

The possibility of ignition increases with increase in temperature, when conditions are created for the formation of the most dangerous concentration of a mixture of the air fuel vapor mixture (0.7-0.8% by volume at atmospheric pressure for most fuel specifications).

Thus, the primary methods of preventing fuel ignition when fueling are:

reliable grounding of the aircraft elements;

decreasing the rate of fueling;

building discharge devices behind the filters;

eliminating sharp edges and protrusions in the tank structure;

rational design of fillers, which promotes the formation of safe corona discharges and prevents spark formation;

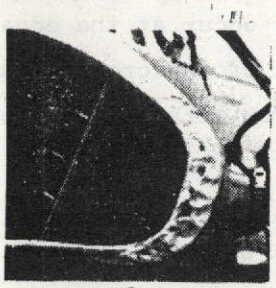
increasing the electric conductivity of fuel (achieved by using special additives);

ceasing filtration in the course of fueling; that is, loading fuel filtered in advance.

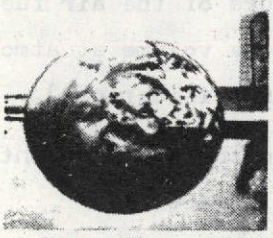
Lightning discharges occur between two clouds or between a cloud and the ground when there is a large electric difference (of the order of a hundred million /24 volts). Current intensity here reaches 50,000 to 200,000 A, and the charge carried is 200-600 Cb.

An aircraft happening to be in the discharge path may be seriously damaged

(Figure 10, a, b, c) or even destroyed by an explosion. Other consequences of the discharge action may be: disruption of radio communication, spontaneous functioning of the electrical devices, locks and the like.



a



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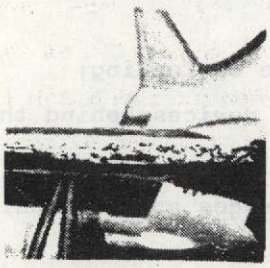

c

Figure 10. Damage to aircraft structure by lightning discharges: a - air intake; b - auxiliary tank; c - wing leading edge.

Electrical charges in a cloud occur because of the intensive friction of the ice particles in it in conditions of severe turbulence.

An electric discharge initially has the form of a thin thread about 50 m long. Lightning occurs when it touches the ground or a cloud of opposite charge. Damage to aircraft is noted most frequently, according to American data, at altitudes up to 6000 m and at temperatures from +5 to -5°C. Statistics show that aircraft encounter lightning approximately once in 2500 flight hours, and helicopters - once in 5000 flight hours. One serious accident occurs as a result of lightning damage per 50,000 flight hours. This figure, naturally, varies widely and depends on the type of aircraft and where it is based. Approximately half of the cases of damage to aircraft by lightning strokes occurs on flights in a zone of active thunderstorm activity. Cases of damage during flight in stratus /25 clouds and even outside of clouds are noted frequently; however, the aircraft usually passed through falling snow or other precipitation at the moment of damage.

There are cases of damage to parked aircraft, by lightning discharges. Fins, control surfaces, propellers, antennas, wing tips, and engine pods are particularly prone to damage. The suspension bearings often fail when the control

surfaces are damaged.

Lightning often magnetizes the steel parts of the structure, with the result that malfunctions occur in the electric and instrument equipment, as well as in the magnetic compasses.

The most dangerous damage when lightning strikes helicopters is that to the rotor and tail-rotor blades. The degree of damage depends on the blade structure.

A blade with a metal spar and a metal or plastic tail piece withstands discharges with a current intensity of 50,000 A without damage to its structure. If the tail piece is made of plastic, small metal strips placed along the outside withstand the passage of the electric charge through the blade structure (the discharge seems to flow around the blade on the outside).

The strength of a plastic blade with filling material of plastic honeycomb cells depends on whether the lightning goes through the blade or goes around it along the outside surface, which depends on the blade's dielectric properties and on the intensity and direction of the stroke. If the charge passes through the blade, it certainly will destroy it, even if the current intensity of the electric discharge is small, of the order of 50,000 A. However, the blade can be protected against destruction by placing small metal strips every 300 mm along the outside of the blade. These strips should be joined by a metal section along the blade's trailing and leading edge.

A plastic blade with metal honeycomb-cell filling material is destroyed only when a discharge with a current intensity of over 1,000,000 A passes through it. The rotor hub usually is more stable against a lightning discharge than the blade.

Figure 11 a and b shows the most probable directions of lightning discharge /26 into a helicopter or aircraft.

Precipitation, Type and Amount

Precipitation is water in liquid or solid state falling onto the earth's surface from clouds or precipitating directly from the air as a result of the /27 condensation of water vapor. The following may fall from clouds: rain, snow, drizzle, glazed rain, granular snow, snow pellets, small hail and hail.

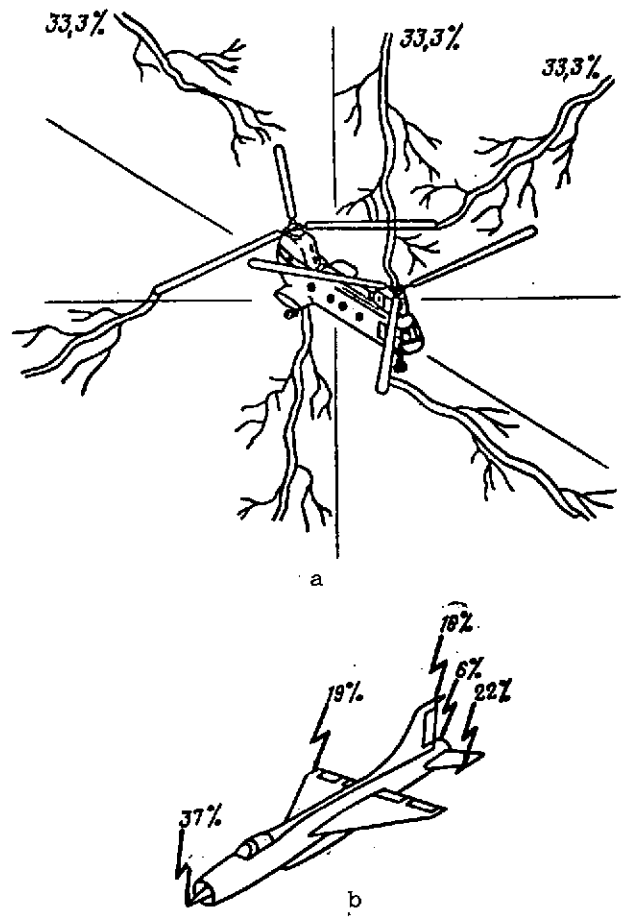

Figure 11. Most probable directions of lightning discharge into a helicopter (a) and an aircraft (b).

Precipitation is divided into showers, continuous precipitation and drizzle, according to how it falls.

The thickness of the layer of precipitated water is measured in millimeters for the amount of precipitation. Precipitation is distributed over the earth quite unevenly with respect to amount. For example, an average of more than 12,000 mm a year falls on the island of Kauan (Hawaiian Islands), and more than 11,000 mm in Charrapundji (India), while there is sometimes no precipitation for several years in the driest regions of the deserts of Peru and Chile and in the Sahara.

All types of precipitation have an unfavorable effect on aviation materiel, especially when it is parked outside of hangars. The most dangerous are showers and precipitation falling in the form of finely-dispersed snow, which has a high penetrating capability.

The following may occur as a result of snow entering the aircraft compartments:

locking of the kinematic links and assemblies;

breakdown of the insulation and locking in the electrical networks;

disruption of the operating modes of various systems because of choking of the drain and vent holes;

clogging of the wells of the undercarriage, deceleration flaps, bomb hatches, etc.

It is difficult to maintain runways and taxiways in good working condition in heavy snowfalls, and the operating effort and time necessary to prepare the aircraft for use increase.

There have been cases of aircraft going out of servicefor a long time because of insufficiently sealed hatches (water penetrated inside the aircraft during a shower, which led to a sharp drop in the resistance of the wiring insulation). Icing of the airfoil and the artificial pavements of runways and taxiways occurs during freezing rain.

Landing an aircraft on a runway (even with concrete pavement) flooded with water or covered with wet snow is also very dangerous, because the phenomenon of aquaplaning (hydroplaning) occurs, loss of control is possible, braking ability is reduced, and tractive resistance when taking off increases considerably. The effect of these factors is complicated on unpaved airfields by the uneven surface and the unstable physical and mechanical properties of the ground. These phenomena and a number of others are in need of thorough study. They are being studied at present, however, only as applied to concrete runways. Some results obtained in investigations for concrete runways can nevertheless be used when analyzing the phenomena occurring under similar conditions on unpaved runways, especially in spring, when the firmness of the still-frozen ground approximates the firmness of concrete pavement. /28

In movement along concrete runways covered with melted snow, water and slush (especially with clay soils), particles of mass (snow, water, mud) penetrate the supporting surface of the tire under the action of hydrodynamic forces and deprive it of direct runway traction. Aquaplaning (hydroplaning) is the extreme degree of manifestation of this fact. Thus, aquaplaning is slipping of the aircraft's

landing wheels along a water layer without touching the runway surface.

The physical principle of aquaplaning is that a water wedge forms under the aircraft's landing wheels when it moves along a runway covered with a layer of water or wet snow. The pressure in the water wedge increases with increase in the aircraft's speed, and at a certain speed, the so-called critical aquaplaning speed, it equals the pressure in the tires. The wheels rise above the runway surface from this moment and begin to slide along the water layer, even the unlocked wheel ceasing to rotate (Figure 12).

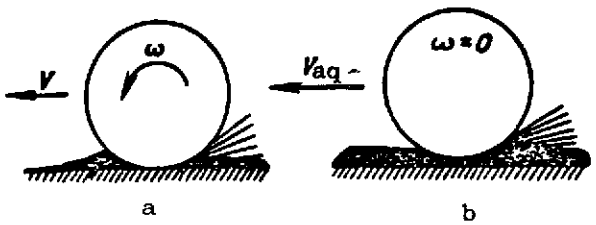

Figure 12. Occurrence of aquaplaning of aircraft landing wheels: a - formation of the water wedge under the wheel; b - aquaplaning - slipping of the wheels along a water layer without rotating or touching the runway surface.

The main signs of aquaplaning are:

formation of a frontal wave ahead of the wheel;

decrease in the area of contact of the tire with the runway surface;

the occurrence of a moment hindering wheel rotation;

an abrupt increase in the aircraft's tractive resistance until the onset of a certain critical speed of the order of 200 km/h, and then a decrease in it. The reason for this phenomenon is the disappearance of the frontal wave at a speed exceeding the critical aquaplaning speed; /29

loss of aircraft stability and control with respect to course when moving along the runway.

Aquaplaning occurs at some minimum thickness of the liquid layer, depending in the first place on its composition (water, snow saturated with water, slush). The possibility of aquaplaning appearing also depends on such factors as the quality of the runway surface, the shape of the tire and the pressure in it, the number and arrangement with respect to each other of the wheels on the aircraft, and the like. These same factors also affect the magnitude of tractive resistance. The thickness of the water layer at which the occurrence of aquaplaning is most probable varies from 2.5 to 50 mm. The moment at which the tire breaks away from the runway surface depends in many respects on the pressure in it, since the break-away occurs at the moment when the hydrodynamic pressure of the frontal wave becomes equal to the internal pressure in the tire. Thus,

an increase in the working pressure in the tire also increases the critical speed of the beginning of aquaplaning.

Special investigations have established that the aquaplaning speed [km/h] depends mainly on the pressure in the tires, and may be determined by the formula /30

$$V_{aq} = 62{,}2\sqrt{p},$$

where p is the pressure in the tire [kgf/cm^2].

Figure 13 shows how the speed of the beginning of aquaplaning depends on the pressure in the tire (for aircraft with a four-wheel bogie).

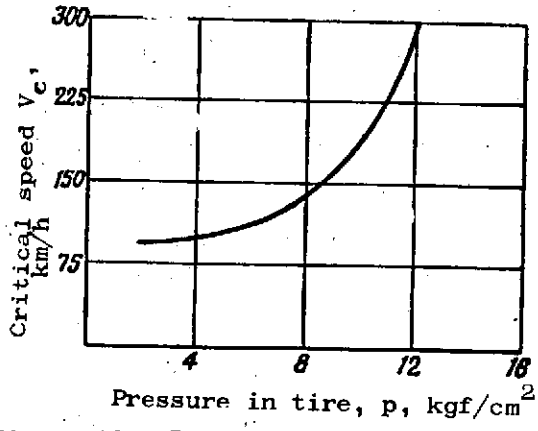

Figure 13. Relation between critical aquaplaning speed and pressure in the tire.

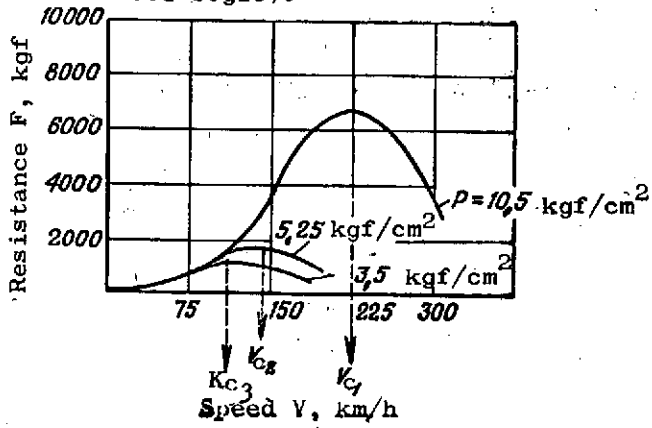

Figure 14. Relation between tractive resistance of the aircraft and pressure in the tire at different speeds (V_{c_1}, V_{c_2}, V_{c_3} are the critical speeds).

The tractive resistance of an aircraft along an unpaved runway covered with melted snow, water or slush also is linked closely with the magnitude of pressure in the tire. Figure 14 shows this relation (with regard to aircraft speed).

The maximum magnitude of resistance decreases as a result of decreasing the pressure in the tire. The drop in resistance is explained, probably, by the disappearance of hydrodynamic pressure in the frontal wave.

The foreign press gives data from experimental research on the magnitudes of pressure in a tire and the speed during aquaplaning of a number of different classes of aircraft (Table 1).

TABLE 1 /31

Type of aircraft	Take-off weight [t]	Nose wheel		Wheel of main undercarriage legs	
		Pressure in tire [kgf/cm^2]	Aquaplaning speed [km/h]	Pressure in tire [kgf/cm^2]	Aquaplaning speed [km/h]
Trainers	5.4-8.0	5.3-5.6	145-148	10.8-11.5	207-214
Fighters	10.9-23.6	10.0-14.0	198-238	14.0-26.2	238-324
Transports	24.5-54.5	3.2-4.9	111-139	4.6-7.3	135-170
Fuelers and Bombers	72.5-221.3	9.1-14.2	190-237	10.1-18.9	200-274

The shape of the tire also affects the aquaplaning speed. The shaped surface of the tire permits increasing the speed of the beginning of aquaplaning and at the same time decreasing tractive resistance, because part of the dynamic /32 head of the frontal wave is released through the groove of the protective cover.

The arrangement of the wheels on the bogie with respect to each other has as much influence on tractive resistance (Figure 15). It is characteristic that the front wheels create the best movement conditions for the rear wheels when they are arranged in tandem. As a result, the resistance of such a bogie is less and the speed when aquaplaning occurs is higher than when the wheels are arranged side-by-side.

The distribution of the resistance created by the liquid layer between the undercarriage legs is approximately: 25-38% falls on the nose wheel, and 75-62% on the wheels of the main undercarriage legs.

An increase in the vertical load on the wheel, linked with an increase in the weight of the aircraft, has almost no effect on the speed at which aquaplaning occurs, because the specific load on the support area does not change for /33 practical purposes (the identation area of the tire on the ground increases).

The tractive resistance of an aircraft along a runway covered with a layer of liquid sharply worsens the aircraft's take-off characteristics, so that the aircraft may not take off at all (Figure 16). Deceleration may increase by

100% even on a concrete runway when the depth of the liquid layer is of the order of 50 mm. Figure 17 shows an example of the relation between the take-off run and the thrust-to-weight ratio for a runway covered with a liquid layer 12 mm thick. Landing on such a strip is as dangerous as take-off, because of the sharp decrease in the friction factor. The change in the friction factor is characterized by segment a on a wet runway and by segment b on a runway covered with a thick layer of water (Figure 18). The danger of the aircraft overrunning the runway increases because of loss of control and reduction in braking effectiveness. Thrust reversing is an effective means of improving landing characteristics in this case (Figure 19).

Wheel arrangement scheme ←	Maximum resistance (relative)
DT	1,00
DT	1,08
DT	1,15
DT	1,59
DT	2,04
DT	2,66
DT	3,33

Figure 15. Change in the relative resistance of the liquid layer on the runway in relation to the number and arrangement of the wheels on the bogie.

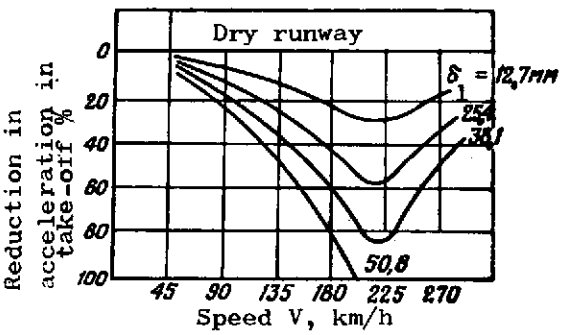

Figure 16. Relation between aircraft take-off characteristics and the depth of the liquid layer on the runway and the take-off speed.

Cutting transverse furrows on the runway 3-6 mm deep and 25-50 mm apart, which break up the water film, can be recommended as one of the methods of fighting aquaplaning. This procedure is expensive, however, and is generally impracticable on unpaved runways.

It is known that the air above each hectare of the earth's surface contains an average of at least two hundred tons of water in the form of clouds, which enter the atmosphere as a result of evaporation from the surface of oceans, seas, lakes, rivers, forests and meadows. /35

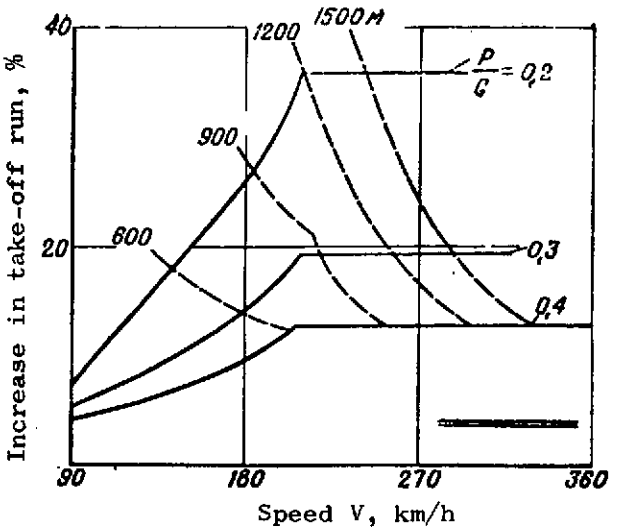

Figure 17. Relation between take-off run along a runway covered with a layer of liquid and the aircraft's thrust-to-weight ratio (the double line shows a landing run along a dry runway; pressure in the tires is 11.2 kgf/cm^2; and aquaplaning speed is 214 km/h).

Clouds are divided by structure into water clouds, consisting of tiny drops of water; ice (crystalline) clouds, consisting of ice crystals; and mixed clouds, consisting of drops and ice crystals. Under certain conditions, the water may be in a supercooled liquid state at extremely low temperatures. For example, it is possible for droplets 1 mm in diameter not to freeze until a temperature of -20°C, and for droplets 10-20 microns in diameter not to freeze until a temperature of -30°C. A mixed cloud is unstable. It changes into an ice cloud in approximately one hour, because the water droplets gradually change into ice crystals.

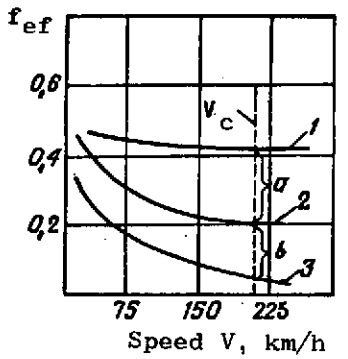

Figure 18. Change in effective friction factor on a dry concrete runway and one covered with a layer of liquid: 1 - dry runway; 2 - wet runway; 3 - runway covered with a thick layer of liquid.

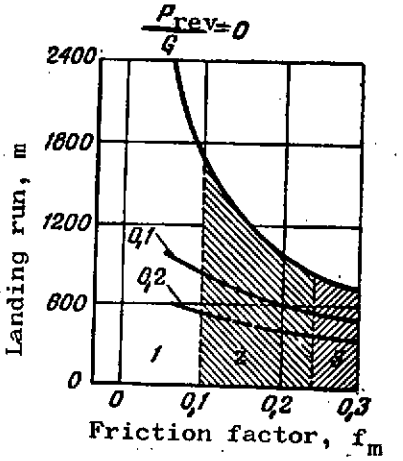

Figure 19. Influence of the friction factor (f_m) and thrust reversing on an aircraft's landing run under different runway conditions: 1 - runway covered with a thick layer of liquid; 2 - wet runway; 3 - dry runway.

When supercooled water drops collide with an aircraft, the water immediately freezes and icing of the aircraft occurs; that is, the relatively rapid formation of ice on individual parts of the aircraft and the engine (on the wing, tail

unit, engine air intake and others). Icing occurs most frequently in flight through clouds, fog, rain and wet snow. Flight in mixed clouds is the most dangerous. An aircraft skin temperature lower than 0°C and the presence of supercooled drops in the air constitute favorable conditions for icing.

The rate of ice formation in the direction perpendicular to the streamlined surface is called the rate of icing [mm/min]. There are four degrees of icing, depending on the rate. Table 2 indicates the degrees of icing and their corresponding rate, the relative probability of the given degree of icing occurring, as well as the time available to the pilot for taking the necessary measures.

TABLE 2

Degree of icing	Rate of icing [mm/min]	Relative probability of icing [%]	Time available to pilot for taking necessary measures [min]
Slight	to 0.5	50	10-20
Average	from 0.5 to 1	35	5-10
Heavy (dangerous)	1	13	2-3
Threatening (emergency)	1	2	0.5-1

The ice accretion of icing is divided by type into: frost-like, which occurs /36 as a result of the instantaneous freezing of supercooled drops when they touch the skin; transparent, which occurs upon the relatively slow freezing of large drops; and mixed.

The rate of icing depends on flight speed and altitude, air temperature and humidity, cloud type, and other factors.

The rate of icing increases with increase in flight speed up to a certain value, because the number of drops ending up on the aircraft surface increases. A further increase in flight speed increases kinematic heating and decreases the rate of icing. The speed at which kinematic heating begins to affect the rate of icing depends on air temperature. Thus, there is insufficient kinematic heating at an air temperature lower than minus 35-40°C (ice cloud), even when

M = 1.2-1.4, to heat the aircraft surface to a temperature above 0°C, at which icing does not occur. In flight at a speed of more than 800 km/h in a water cloud with supercooled drops, icing is improbable until -12°C.

Statistics show that approximately 60% of the cases of icing occur at altitudes less than 3000 m. The probability of icing decreases with increase in altitude, and is no more than 7% at an altitude of 8000 m. Icing occurs most frequently at an outside air temperature of from 0 to -15°C. Icing of the engine may occur also at a positive temperature of +3 to +5°C because of expansion of the air in the input channel, which is accompanied by a decrease in temperature of 8-10°.

The leading edges of the wing and tail unit, the gun barrels, the lips of the engine air intakes, the leading edges of the propellers, and others are subject to icing during flight first of all.

There are three basic types of ice deposits. In the first type, the excresence is wedge-shaped in form (Figure 20a); it distorts the aerodynamic shape of the section less than excrescences of the second and third types; and it is formed during flight in clouds consisting of tiny supercooled drops or a mixture of tiny drops and ice crystals. In the second and third types, the excrescences on the landing edge of the section are gently U-shaped (Figure 20 b, c); they severely distort the aerodynamic shape of the section; they are formed during flight in a medium containing large supercooled drops, which are able to expand slightly before freezing; and the ice sometimes spreads for 250 mm chordwise. /37

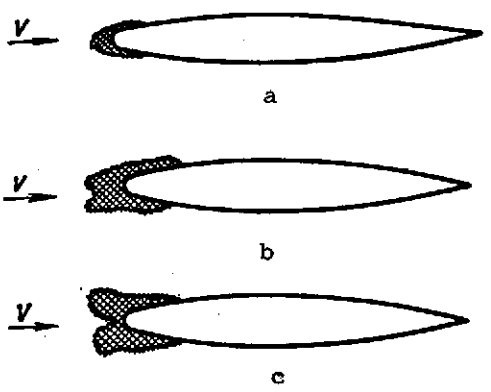

Figure 20. Types of icing: a - at low flight speeds and when the supercooled drops are small in diameter; b - at low flight speeds and when the supercooled drops are large in diameter; c - at increased flight speeds.

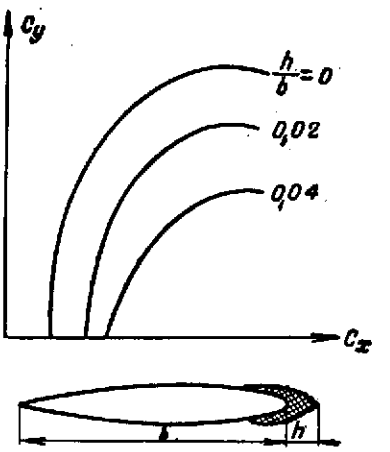

Figure 21. Change in aircraft drag polars upon icing.

It has been established that the aircraft drag polars change considerably upon icing. Figure 21 shows that c_x increases, while c_y decreases; the critical angle of attack also decreases. /38

Deterioration of the aircraft's aerodynamic characteristics upon icing causes a decrease in maximum speed, rate of climb, service ceiling, and flight range and duration.

Distortion of the aircraft lines by ice can increase the speed required for lift-off by up to 30% and more, and double the take-off run. Control power, aileron rolling power and flap efficiency drop sharply when this occurs. The "wingheaviness" phenomenon (involuntary banking of the aircraft) occurs frequently.

Flight tests conducted in the U.S. have established that the formation of a layer of ice only 1.5-2 mm thick on the blades of a helicopter makes vertical climb impossible.

Icing of the pitot-static tube leads to the failure of instruments of the barometric group (speed indicator, altimeter, Mach number indicator, barometer and others). Icing of the guns can cause explosion of the barrels during firing. Icing of the input channel of a gas-turbine engine decreases the air flow, thus reducing thrust by 20-30% and causing an increase in temperature behind the turbine, an increase in specific fuel consumption, and engine surge. The entry of pieces of ice that have broken loose into the compressor leads to damage to the blades and even to total destruction of the compressor. Heavy icing of the propellers causes their blades to be unbalanced.

Ground Strength and Aircraft Passability

The possibility of using aircraft at airfields without paved runways depends in many respects on ground strength and the passability of the given type of aircraft. Ground strength σ is characterized by its ability to resist deformations under the action of the supporting surface of the wheel (ski). Ground strength depends on the presence of a sod cover, the type of soil, its saturation with moisture, temperature, and degree of compactness, and for practical purposes ranges from 1 to 20 kgf/cm^2.

The U-1 is the type impactor most frequently used to determine ground strength. The impactor consists of a guide rod, a tip and a free-falling weight. The area of the tip is 1 cm^2, the weight weighs 2.5 kg and the guide rod is /39

50 cm long. The test involves counting the number of impacts of the weight required to sink the tip to a depth of 10 cm, n_{10}, and to a depth of 30 cm, n_{30}.

The test points are chosen within the airfield work area, along the length, at the end (takeoff) section at 50 m intervals, and in the center, every 200 m; across the width, along the axis of each takeoff and within 25 m on either sides. Two tests (a and b) are made at each point, 1 to 2 m apart. A third test is made when results differ substantially (for n_{10}, more than two impacts, and for n_{30}, more than 20%). Appropriate for ground strength values [in kgf/cm^2] at the test points (Table 3) are obtained by choosing the two results closest to each other.

TABLE 3

n_m	σ'_{10}	σ''_{10}	σ'''_{10}	n_m	σ'_{30}	σ''_{30}	σ'''_{30}
1	3,9	2,2	1,9	7	3,0	2,0	1,4
2	6,0	4,7	4,0	9	5,3	3,0	1,6
3	8,2	7,0	5,7	12	7,3	5,0	2,2
4	9,7	8,7	6,8	15	8,7	8,1	3,8
6	12,0	11,2	8,5	20	10,3	10,3	6,4
8	13,7	13,0	9,9	30	12,0	12,0	9,7
10	15,0	14,5	11,1	40	13,0	13,0	11,5
12	16,0	—	12,1	50	14,0	14,0	13,0

The following nomenclature is used in Table 3:

σ' is the strength of sandy soils;

σ'' is the strength of loamy and podzolic soils;

σ''' is the strength of black earth, chestnut and brown soils.

Then ground strength is determined as a mean for the two tests (a and b):

$$\sigma_{10_m} = \frac{\sigma_{10.a} + \sigma_{10.b}}{2}; \tag{1.8}$$

$$\sigma_{30_m} = \frac{\sigma_{30.a} + \sigma_{30.b}}{2}. \tag{1.9}$$

Ground strength at the testing site (stake) is determined as

$$\sigma_{ts} = \frac{\sigma_{10_m} + \sigma_{30_m}}{2}, \tag{1.10}$$

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and at the airstrip take-off as

$$\sigma_s = \frac{\sigma_{ts_1} + \sigma_{ts_2} + \ldots + \sigma_{ts_i} + \ldots + \sigma_{ts_m}}{m}, \quad (1.11)$$

where

σ_{ts_i} is the smallest value of ground strength obtained in tests at the take-off (50% of all results are selected; i = 1-m);

m is a number equal to half of all testing points at the take-off.

The obtained value of σ_s is compared with the required value, σ_{req}, for the given type of aircraft. If σ_{req} is equal to or less than actual ground strength, the ground is considered suitable for take-off and landing. The value of σ_{req} [kgf/cm^2] for an aircraft is indicated in its operating manual, and in addition, it can be calculated approximately from the formula

$$\sigma_{req} = \frac{q_{mw}}{0{,}255}, \quad (1.12)$$

where

$$q_{mw} = \frac{G_{mw}}{0{,}75LB} \text{ [kgf/cm}^2\text{]} \quad (1.13)$$

G_{mw} is the load on the wheel of the main undercarriage leg [kg];

L is the length of the contact area of the wheel with the ground [cm];

B is the width of the contact area of the wheel with the ground [cm].

The suitability of the ground for flights can be determined in a number of cases by the depth of the track remaining after the aircraft has taxied past, h, and by the magnitude of tire deflection when parked on hard pavement, δ_p.

There are the following types of airfields without artificial surface: stony, sandy, clay, ice, and snow.

The strength of stony and ice airfields (given the necessary thickness of the ice cover) is more than sufficient to operate any type of aircraft. The /41
strength of a runway snow cover is evaluated by the density of the upper layer, γ, 150 mm thick, and should be at least 0.3-0.6 kgf/cm^3.

The strength of sandy and clay soil depends essentially on its moisture content, and is determined by one of three states:

molecular moisture (water covers the surface of the soil particles in the form of a film);

capillary moisture capacity (water accumulates in the free state along the borders of the particles);

saturation capacity (water fills all pores in the soil.

The strength of different types of soils changes differently with change in moisture capacity: clay soil, as well as loess and laterite, which has maximum strength in a dry state and with a molecular moisture level, loses strength as it becomes saturated with water; sandy soil, which has extremely low strength in a dry state, acquires maximum strength in the state of capillary moisture capacity; upon further saturation with water, it again loses strength.

The time the ground remains in a low strength state depends on the type of soil and the climatic zone (and in particular, on air humidity). There is especially low ground strength in spring and autumn (up to 2-3 kgf/cm^2). It can be taken approximately that for the central belt of the European part of the Soviet Union, Siberia and the Urals, ground strength changes in spring and autumn by 1 kgf/cm^2 every two weeks. Naturally, this assumption is quite conditional, and its validity depends on the type of soil, the presence of a sod cover and the relief of the terrain, characteristic for the given airfield.

Airfields with clay soil characteristically remain in non-operating condition for the longest time. It can be decreased either by conducting fundamental operations on increasing the strength of the runways, taxiways and parks, or by increasing aircraft passability. The concept of aircraft passability is rather broad and includes the aircraft's ability:

to start independently after a brief stop;

to reach lift-off speed and take off within the limits of the runway length /42
established for the given type of aircraft, without using auxiliary energy sources;

to fulfill the combat or flight mission (the aircraft's equipment and systems should function normally in this);

to land and taxi in;

not to leave tracks on the runway or taxiway exceeding 5-10% of wheel diameter, or other damage interfering with the subsequent use of the airfield by aircraft;

to complete repeat sorties during the established time interval.

Considerably more force is necessary to break out the aircraft, especially after it has been parked on the ground for a long time, than to ensure its subsequent accelerated motion. It is usually considered that the following inequality must be satisfied to accomplish break-out

$$P \geqslant 1{,}4F = 1{,}4fG \text{ or } \frac{P}{G} \geqslant 1{,}4f, \tag{1.14}$$

where

P is engine thrust [kgf];

G is the aircraft weight [kgf];

F and f are respectively the force and the drag coefficient of the ground (runway surface) to aircraft movement.

The thrust-to-weight ratio of modern aircraft is great; therefore, condition (1.14), called the passability condition, usually is satisfied even with ground of the lowest strength.

The tractive resistance of the ground (runway surface) is characterized by the drag coefficient, f, and by the depth of the track, h, [cm]. For aircraft whose wheels are arranged not one behind the other (tandem), f and h are determined by the formulas:

$$f = \frac{q_{re}}{\mu\xi\sigma}; \tag{1.15}$$

$$h = \frac{q_{re}^2 D_{infl}}{\mu\xi^2\sigma^2}, \tag{1.16}$$

where

q_{re} is the reduced specific load on the wheels [kgf/cm^2];

μ is a coefficient, which takes into account tire deflection under the effect of soil of different density and depends only on the value σ (it is customary to consider normal tire pressure as that which, at a given load, ensures a wheel deflection of δ = 0.07-0.075); /43

ξ is a coefficient, which is the adjustment for the change in tire deflection when the internal pressure or the load on the wheel differs from those calculated;

σ is the ground strength, characterized by its ability to resist deflection under the action of the external load [kgf/cm^2];

q_{mw} is the specific load on the main wheel [kgf/cm^2];

D_{mw} is the diameter of the main wheel [cm].

The reduced specific load on the wheels is equal to

$$q_{re} = k_{mw}q_{mw} + k_{fw}q_{fw},$$

and the specific loads on the main and front wheels respectively are equal to

$$q_{mw} = \frac{\kappa_{mw} G}{n_{mw} DB} \quad \text{and} \quad q_{fw} = \frac{\kappa_{fw} G}{n_{fw} db},$$

where

k_{mw} and k_{fw} are the proportion of aircraft weight falling on the main and front undercarriage legs respectively (for aircraft with a three-support undercarriage, k_{mw} = 0.85-0.9; k_{fw} = 0.10-0.15);

G is the aircraft weight;

n_{mw} and n_{fw} are the number of main and front landing wheels respectively;

D and d are the diameter of the main and front landing wheels respectively [cm];

B and b are the width of the tires of the main and front landing wheels respectively [cm].

For aircraft which have landing gear with four-wheel bogies of bicycle configuration, in which the rear wheels go along tracks laid by the front wheels:

$$f = \frac{q_{re}}{\mu\sigma} \kappa_1; \tag{1.17}$$

$$h = \frac{q_{mw}^2 D}{\mu^2 \sigma^2} \kappa_2^2. \tag{1.18}$$

The values of the coefficients k_1 and k_2 depend on the distribution of the load between the axes of the front and rear wheels and on the ground condition. If the loads on the axes of the front and rear wheels of the main undercarriage

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legs are the same, k_1 = 1.0 and k_2 = 1.75 for ground in a water-saturated state; k_1 = 0.925 and k_2 = 1.54 in a plastic state; k_1 = 0.900 and k_2 = 1.48 in a hard plastic or hard dry state.

The permissible track depth, h_{per}, is selected with regard to the wheel sizes, the combat situation at hand and the assigned tasks. When there is a sod cover, for example, the track depth must not reach a value leading to its destruction. Track depth may be from 5 to 10 cm, depending on the quality of the sod cover.

The permissible track depth sometimes can be determined approximately from the formula

$$h_{per} \leqslant \frac{B}{4},$$

where B is the tire width of the landing wheel [cm].

The shape of the track is linked with its depth. Figure 22 shows three characteristic track shapes: the sod cover is not destroyed in the track with smooth outlines of the walls (Figure 22a), the sod cover is destroyed in the tracks with vertical walls (Figure 22b and c), and especially severely in the track shown in Figure 22c, where banks of forced-out soil have formed.

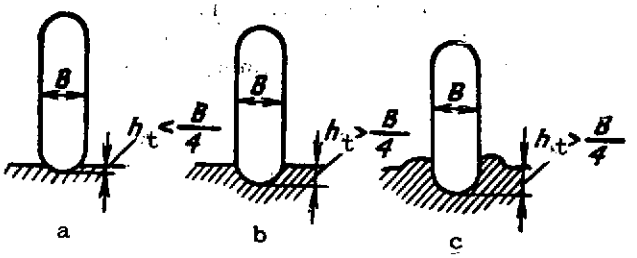

Figure 22. Relation between track shape (a, b, c) and its depth.

Aircraft passability in operating conditions may be improved artificially by temporarily reducing the air pressure in the tires to a certain limit. It must be remembered here that normal pressure in the tires is set with regard to the maximum permissible deformation when they are deflected on a hard pavement. Tires have considerably less deflection on the ground as a result of shrinkage of the soil itself. For example, a deflection of 2.5 cm for the main wheel of a subsonic fighter may correspond on concrete to an internal pressure of 7 kgf/cm^2, and on loose ground to an internal pressure of 2.5 kgf/cm^2. /45

Track depth decreases and the taxiing and take-off processes are made easier as a result of reducing the internal pressure in the tires. It is advisable to check the tractive resistance of the landing wheels when the pressure

in the tires is reduced. One of the simplest methods of such a check is the experimental determination of the drag coefficient when a special two-wheel bogie, which is loaded with ballast to the specified load and is then transported along the unpaved runway, is moved. A dynamometer, with the help of which the resistance force is measured, is placed in the towing device of this bogie. The dynamometer scale may be graduated in the scale of the drag coefficient. The sizes of the bogie wheels should correspond to the size of the landing wheels of the aircraft which is supposed to operate from the given airfield.

Unpaved airfields with reduced ground strength not only make it difficult to ensure passability, but also complicate aircraft operation. Sand, dirt, stones, water, ice and snow act on the aircraft during take-off, landing and taxiing, the result of which may be:

clogging of the ventilation devices (slits, louvres, branch pipes), which disrupts the operating mode of the equipment;

mechanical damage, corrosion and erosion of the aircraft surface, antennae, armament, compressor blades, etc.;

contamination of optical and radio transparent surfaces, cameras and sights;

locking and increased wear of kinematic units, seals of hydraulic subassemblies and bearings;

clogging of the vent and drain holes of the aircraft systems, which disrupts their designed operating conditions;

an increase in operating effort due to an increase in the volume of obligatory operations in cleaning, checking and preparing aircraft materiel. /46

These factors have the greatest effect on the aircraft within the so-called "splashing fan" (Figure 23).

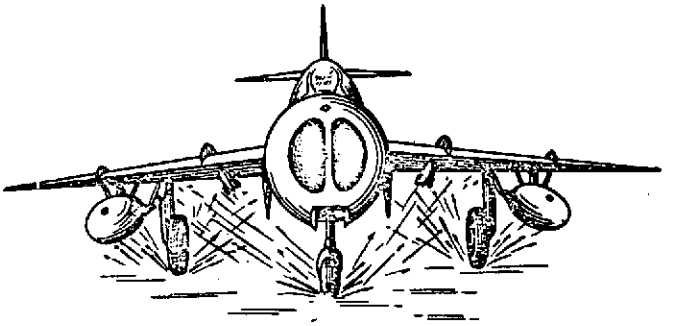

Figure 23. Diagram of "splashing fan."

The surface of airfields often deteriorates due to the movement of snow and sand, the sagging of plates, the destruction of their joints, etc. Therefore, a characteristic factor influencing aircraft operation is an increase in the loads acting on the airframe, systems and equipment when the aircraft is moving along the airfield. The magnitude of these loads depends on the physical and mechanical characteristics and the microprofile of the surface, the speed, the structure of the undercarriage and the airframe, as well as on the characteristics of the shock absorbers.

The following are noted when operating aircraft at airfields with an uneven surface:

a considerable increase in load repeatability, mainly dangerous loads in relation to the fatigue strength of the aircraft structure and its equipment (Figure 24);

an increase in the level of loads on the undercarriage and the elements of the aircraft structure adjacent to it; this applies especially to the leading undercarriage leg;

an increase in the repeatability of vibration accelerations by a factor of 3-10;

expansion of the vibration frequency range of the aircraft structure and its equipment, which makes the selection of shock absorbing devices more difficult (their frequency spectrum lies in the range from 1 to 300 Hz); /47

the occurrence when the aircraft is taxiing of vibration accelerations with a frequency of 1-8 Hz and with large amplitudes, increasing with distance of the point at which they are measured from the center of gravity (Figure 25).

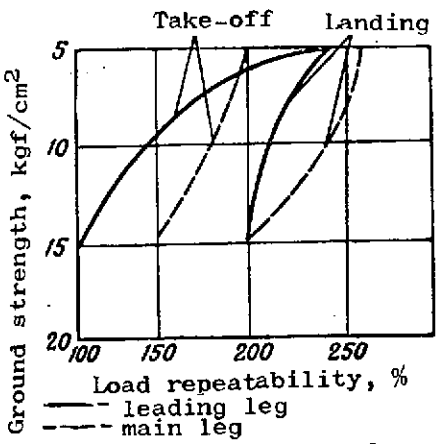

Figure 24. Change in load repeatability on an aircraft structure in relation to runway ground strength.

The latter circumstance creates extremely difficult conditions for operating equipment located at a distance from the aircraft's center of gravity, and is the cause of the occurrence of such defects as the appearance of cracks in structural elements, the failure of radio tubes and electric bulbs, the destruction of soldered and welded joints of wires and high-frequency cables in the connectors, an increase in the error of the

gyroscopic sensors, a change in the working frequencies due to upsetting of the heterodynes and oscillators, the failure of wire and cable insulation because of mechanical damage during their friction between each other and against structural elements, short circuiting of the battery plates, destruction of the waveguides, destruction of the pipelines, weakening of the rivet and bolt seams, reduction in pressurization of the cabins and fuel compartments, increase in play in the joints, increased wear of the bearings, etc.

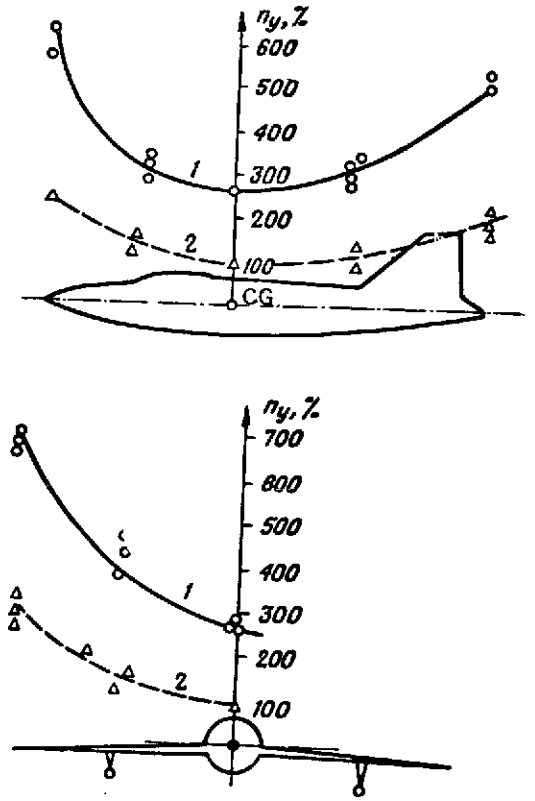

Figure 25. Diagram of change in the vibration accelerations along the aircraft length and span (the value of the vibration acceleration in the aircraft's center of gravity when it is operating on a concrete runway is taken as 100%): 1 - for an unpaved runway; 2 - for a concrete runway.

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The nature of the increase in vibration accelerations along the fuselage length and along the span essentially depends on the natural vibration frequency of the structure. In most modern aircraft, the natural vibration frequency is close in magnitude to the forced vibration frequency in the practical absence of damping from the action of aerodynamic forces. The damping coefficients of aircraft /49 structures made of high-strength materials with a large modulus of elasticity do not exceed 0.07-0.15, which makes these structures quite sensitive to the effect of disturbing forces (Figure 26).

In order to decrease the dynamic loads, it is necessary to decrease the natural vibration frequency of the undercarriage to a magnitude which is less than the natural vibration frequency of the airframe (for example, by increasing the shock absorber stroke, and by using two- and three-chamber shock absorbers, as well as anti-g valves, which disconnect the hydraulic part of the

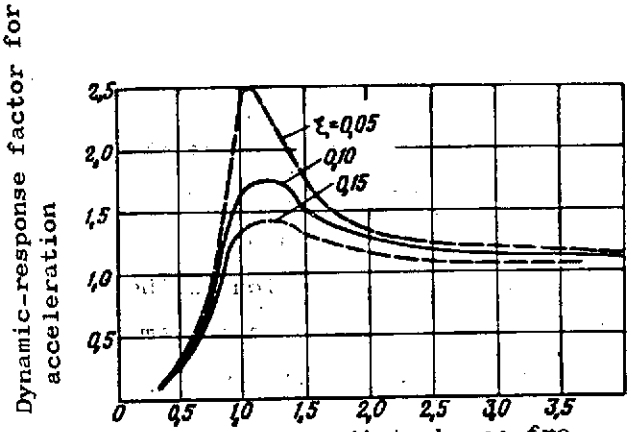


Figure 26. Reaction of the aircraft structure to harmonic disturbances caused by runway irregularities in relation to the damping coefficient of the structure.

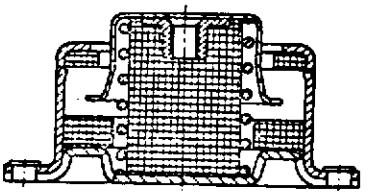
shock absorber when the aircraft is moving at low speeds along an uneven surface). This problem will be solved completely, if we succeed in making a shock absorber with a variable degree of stiffness.

It is advisable to use levered wheel suspension to decrease the drag loads on the undercarriage legs. An increase in frictional force (and consequently in shock absorber stiffness) under the action of drag loads does not occur in this case, as opposed to a telescopic strut.

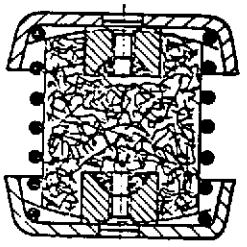
Special attention should be devoted to the relability of the shock absorbers of aircraft equipment elements. The rubber and metal shock absorbers widely used under normal conditions are unsuitable for use in complex operating conditions. This is explained by the fact that the physical and mechanical characteristics of such shock absorbers are reduced sharply at negative temperatures (below -25°C), as well as because having a high natural vibration frequency at a nominal load (15-20 Hz vertically and 30-35 Hz horizontally), they do not protect the equipment from the action of vibrations beginning at 10 Hz and less. In addition, the mechanical strength of the shock absorber structure where it is attached to the metal fittings is insufficient, the resistance of the rubber to the action of direct solar rays and ozone is low, and the phenomenon of subharmonic resonance occurs at vibration amplitudes exceeding 0.5 mm. /50

The characteristics of rubber and metal shock absorbers have been improved somewhat thanks to a change in their structure (horn-shaped shock absorbers) and the use of more perfected grades of rubber (for example, silicons, which have a working temperature range of from -80 to +250°C).

The AFD (Figure 27c), ARDN, Vibrachoc (Figure 27 a and b), Barry and other damped spring shock absorbers are more suitable for protecting equipment. The flexible members of these shock absorbers are conical or exponential-shaped springs. Damping is by the friction generated by the housing of a nylon /51



a



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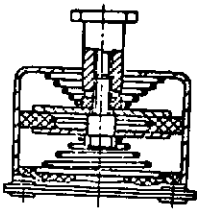

c

Figure 27. Structure of damped spring shock absorbers: a,b - Vibrachoc; c - AFD.

diaphragm, felt cap, or metal wool. A small cylinder of cold-resistant rubber also can be used as a damper. These types of dampers ensure the equipment's anti-vibration insulation from frequencies of 5-10 Hz and higher and at amplitudes up to 1.5 mm. The working temperature interval is -60 to +70°C, and air humidity, ozone and solar rays have no effect on their operation. The working service life of dampers is more than 300 hours (only 50 hours for rubber and metal block shock absorbers).

The undercarriage portrayed in Figure 28 should be considered as an example of a successfully selected undercarriage structure in terms of protecting it from vibrations. The undercarriage consists of two box-shaped sections, connected by two shells. The space between the shells is used for the passage of cooling air. Rigid support beams, on which the shock absorbers are arranged, pass through the box-shaped sections. This undercarriage structure has the following merits:

the very high natural vibration frequency of the comparatively light beam, fitted with the shock absorbers;

the undercarriage has a reduced required stiffness and natural vibration frequency in comparison to the usual structure;

full use of the undercarriage volume;

good cooling of the equipment because of the convenience of formation of the large-area channels.

The total weight of such an undercarriage structure under an equipment block weighing 120 kgf is 9 kgf, and the natural vibration frequency is 200 Hz (the weight of an undercarriage of the usual structure with a natural vibration frequency of 60 Hz is 15-16 kgf). /52

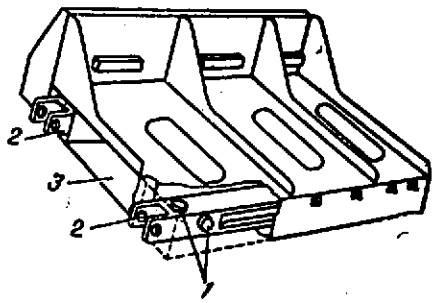

Figure 28. Structural diagram of a damped undercarriage for installation of fittings: 1 - shock absorbers; 2 - beams; 3 - ventilation chamber.

The foreign press mentions a new principle of vibration damping by scattering their energy during a shift of the plate elements fastened together in layers of visco-elastic material. It is reported that the phenomenon of relative displacement of the plates occurs (similar to what occurs with the pages of a bound notebook). Such a method of shock absorption is highly effective, according to foreign sources.

Dustiness

Dust causes considerable difficulties in operation even on bases at paved airfields. At unpaved airfields, where dustiness increases ten times in comparison with paved airfields, dust has a considerable effect on aircraft structure and equipment and on the organization of work on aircraft materiel.

The quality of lubrication of the hinged joints sharply deteriorates, and wear on parts and play increase as a result of the entry of dust and sand into hinged joints. Scratches occur on contact surfaces and, as a result, locking of the kinematic links is possible. Dust causes intensive damage to all types of coatings and, absorbing moisture, furthers the start of corrosion on parts.

Dust particles, passing through the compressor blades or the cooling turbine impellers, cause erosion and abrasive wear of these parts and sharply reduce their service life.

Roller bearings, an ideal place for the accumulation of dust, are especially sensitive to its effect. Increased wear, "squeak," and locking of the roller bearings are the main results of the entry of dust into them.

Seizing of the servodrive slide couples and pistons, increased wear of precision parts, and upsetting of the subassemblies of the hydraulic and fuel systems also are frequently the result of the entry of dust into the working fluid and the fuel. The packing of the actuation cylinder rods suffers especially from the effect of dust. /53

When it enters the gas-air passage of jet engines, dust reduces their power and increases specific fuel consumption as a result of erosion of the blades and other structural elements, as well as because of a change in the passage configuration and a decrease in heat conductivity, which occurs when dust particles accumulate in the compressor, as well as in the turbine. If dust enters the automatic equipment elements of the engine, they go out of service comparatively quickly.

Dust settles in the compressor on the internal surface of its casing and is compacted under the action of centrifugal forces. The compressor has the greatest centrifugal action in the first two stages.

It is mainly the compressor blades that are subject to erosion, which reduces its efficiency and surge margins. The soft material sealing the ends of the compressor blades quickly goes out of service, which also sharply reduces engine characteristics.

Erosion of the nozzle and rotor turbine blades is the same in nature as erosion of the compressor blades, but is less intensive because more of the dust is held in the compressor, and also because the material of the turbine blades is harder.

The degree of erosion action on engine characteristics depends on the mass of dust which entered the engine during operation. The intensity of erosion depends mainly on the hardness and chemical composition of the dust particles, and to a lesser degree on the particle size distribution (particles up to 20 μ in size do not cause any significant erosion). Thus, quartz sand causes extremely rapid destruction of the blades, and sand with an admixture of salts accelerates the corrosion processes in elements of the gas-air passage.

As a result of dust adhering to the compressor blades, their natural oscillation frequency may decrease by 45%, which leads to an inadmissable increase in the stresses acting in the blades and to their breaking.

Dust accelerates wear of the labyrinth packings, and oil contaminated by /54
dust accelerates wear of the gear box and transmission elments, as well as the rotor bearings.

When the air supplied to the fuel regulator, the by-pass valve, the cabin pressurization system, and the SPS system contains dust, the different components

of these units may fail prematurely (before their service life has expired).

A compacted layer of dust covering the sides of the burners may sharply reduce fuel pulverizing quality and burner cooling.

When dust enters the piston engines, power and service life also may be reduced, and specific fuel consumption may increase. Thus, according to American data, helicopter engines, which have a service life under normal conditions of 1000-1600 hours, last only 300 hours under the conditions of South Viet Nam. The premature replacement of engines and parts, caused by their erosion, costs the U.S. military department 100 million dollars every year.

When they fall on the surface of optically transparent parts, dust particles leave scratches on them, as a result of which the canopies, camera windows, armoured glass, photographic equipment, and the like go out of service. Dust and the corrosion it causes increase the electrical resistance of contacts and lead to "sealing" of the relays, contacts and switches. Dust also reduces the electrical resistance and mechanical strength of insulation materials.

The magnetic and frequency characteristics of electronic equipment may change sharply, and the control and adjustment of on-board radar may be upset, as a result of a change in the size of the clearances (under the action of dust).

The accuracy of instruments is reduced sharply and the failure rate increases under the action of dust. Dust disrupts the operation of vitally important aircraft systems by clogging the static and dynamic pressure pick-ups, drain holes, and ventilation grids. Dust and sand cause wearing of the parts that move back and forth in rifles and machine guns, and can cause them to jam.

Dust consists mainly of particles of silicon oxide, which explains its strong abrasive action. The degree of fineness of the particles varies from 5 /55
to 50 microns, which ensures their high penetrability.

Strong winds in areas with a dust layer up to 15-20 cm thick immediately turn into dust storms, as a result of which huge masses of dust are carried for hundreds of kilometers and rise to an altitude of 6-8 km, which makes normal operation of aircraft materiel impossible. Even gentle winds, forming "drifting snow" and lifting dust to an altitude of 1-2 m, bring a large amount of dust into aircraft. On the average, the amount of dust inside subassemblies and

instruments on dusty airfields reaches 11 mg/dm^2, and the thickness of its layer - 3-5 mc.

When it enters the working areas, dust dirties the stands, measuring instruments and subassemblies of aircraft on inspection and in repair. Protection of aircraft materiel from dust and its systematic removal require considerable labor expenditures.

Salinity of Soil and Water

Salts may enter an aircraft and its subassemblies in the following ways:

from humid air saturated with salt water vapor;

from dust, a certain amount of the particles of which consist of tiny salt crystals;

from local reservoir water when it is used for technical requirements without preliminary desalting.

The soil in individual regions of the earth contains more than 12-35% by volume of water-soluble salt. Salts create severe corrosion conditions when they enter aircraft subassemblies and system elements. The moisture absorbed from the air by salt particles forms an electrolyte, in which corrosion processes are accelerated many times. (This process takes place even in deserts, because abundant dew falls and salt particles dissolve at night there as a result of the great temperature differences characteristic of a continental climate). The corrosion process takes place so intensively under these conditions that damage centers of inadmissable dimensions may occur even during the time between adjustments. Metals and their coverings are destroyed, as well as plastics and even the /56 concrete pavements of runways, taxiways and parks.

The water used for technical requirements in some areas contains so many chlorine, calcium and sodium ions, that it becomes an aggressive medium and a serious source of corrosion.

Biological Factors

The difference between the tropics and the non-tropical regions is shown especially vividly in the increase in the activity and growth rates of representatives of the plant and animal kingdoms. The large amount of heat, moisture and light created good conditions for the development of the organic world. This

is shown first of all in the rapid growth of mold, mushrooms, lichens and mosses, which damage aviation materiel. Damaging metal and plastic surfaces, they further their rapid destruction, because a considerable amount of chemically active substances are released in the process of their vital activities. Obviously, some of these organisms are capable of breaking up polymers. Dust, accumulating in structural compartments and equipment blocks, serves as a nutrient medium for small plants as well, which cause intensive corrosion of structural elements when they put out roots. Rapidly-growing shrubs, bamboo and other plants destroy the artificial surface of airfields and structures.

The insect world is unusually varied in the tropics. Many of its representatives, termites, ants, borers and the like, energetically destroy parts made of fabric, rubber, plastic and other organic materials. Insects clog system drain holes and the lines of the pitot-static tube, and put them out of service. Snails and worms also damage parts made of organic materials.

Rodents (rats, mice), which damage the wiring, hoses, tires, parts made of fabric and rubber, and the like, inflict a great deal of damage on aviation materiel.

Poisonous animals, which often crawl into aircraft and aircraft materiel on the ground, cause aviators a great deal of trouble in the tropics. Additional safety measures must be taken as a result before beginning work on aviation /57 materiel.

Birds are one of the main damaging biological factors. They damage the tires and the compressor blades by littering the runway with animal bones and nutshells. However, collisions with birds in flight and in take-off and landing are especially dangerous. The increase in flight speeds and the mastering of flight at low altitudes has led to the fact that birds are unable to react at the approach of an aircraft. The birds ended up in the engine in approximately 40% of the recorded cases of collisions (this can be explained by the large sectional area of the air intake input channel, as well as by its suction). Cases of birds striking the cabin glazing are frequent. More than half of the cases of collisions between aircraft and birds occur during take-off and landing. The warm season and especially the periods of bird migration are the most dangerous in this respect.

The consequences of collision with a bird are determined by its weight, the aircraft's flight speed, and the angle and place of contact.

The result of a bird entering the engine, as a rule, is dents and nicks on the compressor first stage blades, rotor unbalance, and very often engine surge and stopping. The engine requires replacement after all such collisions, as a practical matter.

The result of birds striking the cabin glazing in most cases is its destruction. A bird the size of a goose or a duck can break even a windshield (attempts to create a glazing stable against being struck have not yielded favorable results up to the present).

Collisions of birds with the tail unit, control surfaces, and the wing leading edge are extremely dangerous. The pilot, especially at a low altitude, often is unable to cope with the consequences of such a collision.

According to reports in the foreign press, the U.S. Air Force has lost over 100 engines as a result of collisions with birds in the last ten years alone; Canada has lost 7 F-104 aircraft; the British Air Force estimates the total annual losses at 1 million pounds sterling. Specialists at more than 300 laboratories in 31 countries of the world are occupied with the problems of frightening away birds and reducing the losses from collisions between them and aircraft. /58

Wind

Heavy gusts of wind often inflict damage on aircraft during take-off and landing, as well as when they are parked (wind speed during gusts may exceed 70 m/s). Thus, 69 cases of the failure of aircraft materiel due to strong winds were recorded in the U.S. Air Force from 1961 through 1964.

Winds usually occur because of a difference in atmospheric pressure (the baric gradient) above different sections of the earth's surface. Winds of enormous force may occur when the gradient is large. Thus, the wind may maintain a speed of 50-60 km/h and more over a long period of time during hurricanes in the tropical regions, where high pressure gradients may be maintained for a long time (which is caused by the energy drawn off from the heated surface of the ocean and by the rotation of air masses around the center of the hurricane).

Winds of local origin, occurring because of the accumulation of cold air in mountain valleys and its sudden breakthrough onto a plain or sea surface (bora), may attain extremely great force.

Wind of great force may tear away aircraft that are not reliably enough secured in parks, cause them to collide and capsize, tear the covers off them, damage the control surfaces, and the like. Cases of damage to aircraft skin and glazing by stones and unfastened items of airfield equipment are frequent during gusts of wind.

In view of the fact that the meteorological service cannot always provide storm warnings in time, especially with respect to winds of local origin, and also because there are regions where the meteorological network is insufficient, continuous work in ensuring storm safety acquires special importance.

Wind complicates the operation of aircraft materiel considerably. A cross /59
wind or a wind from the side of the propelling nozzle makes conditions for starting the engine worse, increases the temperature of the gases behind the turbine, and may cause engine surge. The aircraft must be swung around so the air intakes are upwind before starting the engine in order to avoid this.

Aircraft have a tendency to turn downwind during take-off and taxiing. This makes it difficult to maintain course during take-off, and is especially dangerous for light aircraft and aircraft with large side surfaces. Flights of some aircraft are possible only with a cross wind not exceeding 10-15 m/s. In addition, the take-off run increases in a cross wind, because the pilot is forced to use the controls and wheel brakes to maintain course (the take-off run of a heavy aircraft in a cross wind of 10-12 m/s increases by 100-150 m). A tail or head wind may change the take-off and landing run and the take-off and landing distance considerably. When the wind direction is along the runway, lift-off speed relative to the ground, $V_{gr.lo}$ differs from lift-off airspeed, V_{lo} by the magnitude of the wind speed, $\pm W$ (the "+" sign corresponds to a tail wind and the "-" sign to a head wind):

$$V_{gr.lo} = V_{lo} \pm W. \tag{1.19}$$

The take-off run is determined by the magnitude of the ground speed:

$$L_{t_w} = \frac{V^2_{gr.lo}}{2j_a} = \frac{(V_{lo} \pm W)^2}{2j_a} = \frac{V^2_{lo}}{2j_a}\left(1 \pm \frac{W}{V_{lo}}\right)^2$$

or

$$L_{t_w}=L_{t_0}\left(1\pm\frac{W}{V_{1o}}\right)^2, \tag{1.20}$$

where

L_{t_w} and L_{t_0} are the take-off run during wind and during a calm, respectively [m];

j_a is the average acceleration during take-off [m/s^2];

W is wind speed [m/s];

V_{1o} is lift-off speed [m/s].

The effect of the wind is greater the less the lift-off speed.

The landing run may be determined by the formula /60

$$L_{1_w}=L_{1_0}\left(1\pm\frac{W}{V_{1an}}\right)^2 \text{ [м]}, \tag{1.21}$$

where V_{1an} is the landing speed [m/s].

The wind has a greater effect on the landing run than on the take-off run, since lift-off speed is greater than landing speed.

Since flight range is determined by speed V relative to the ground, and the hourly fuel consumption does not depend on the wind, the fuel consumption per kilometer in wind is equal to [kgf/km]:

$$q_w=\frac{G_h}{V\pm W}=\frac{G_h}{V\left(1\pm\frac{W}{V}\right)}=q\frac{1}{1\pm\frac{W}{V}}, \tag{1.22}$$

where

G_h is the hourly fuel consumption [kgf/h];

W is wind speed [km/h];

V is flight speed [km/h].

Then flight range in wind is [km]:

$$L_w=L_{hf}\left(1\pm\frac{W}{V}\right).$$

where L_{hf} is the horizontal flight range in a calm.

Wind sometimes becomes the determining factor in the possibility of fulfilling the flight mission for low-speed aircraft with a small fuel capacity.

Rough air, that is, the action on the aircraft of vertical air currents during flight in rough turbulent air, may create serious danger for aircraft flight. Turbulence at low altitudes occurs mainly in the warm season due to uneven heating of the earth's surface (forests, reservoirs, plowed areas, etc.). Turbulence at medium altitudes occurs on the borders of cold and warm fronts, as well as in cumulus and thick-cumulus cloud cover. At high altitudes, horizontal flow of air masses at different velocities with respect to altitude is observed near the tropopause (H = 11,000-13,000 m). Considerable turbulization, also causing rough air, occurs when there is a large velocity difference.

Atmospheric turbulence is characterized by the velocity of the vertical air currents and the frequency of turbulence. The velocity of the vertical currents /61 determines the magnitude of the g-load, the probability of approaching the critical angles of attack, the change in aircraft flight altitude, and engine stability. The velocity of ascending currents from the ground may reach 15-20 m/s at medium and high altitudes, and 30-45 m/s in a thunderstorm front. The velocity of descending currents usually is somewhat less than that of ascending currents.

There are four types of turbulence (Table 4).

TABLE 4

Type of turbulence	Action of turbulence on aircraft and equipment	Absolute value of G-load increment (Δn_y)
Slight	Aircraft rocks slightly; separate slight bumps	≤ 0.2
Moderate	Rocking is intensified; bumps are more frequent and more severe	≤ 0.5
Severe	Aircraft sometimes "drops", severe bumps, crew members either pressed into seats or thrown out of them	≤ 1
Storm	Aircraft is thrown about continually, crew members strongly pressed into seats or torn out of them	> 1

The g-loads due to vertical gusts may be from -2 to +4g during storm turbulence.

The magnitude of the increment in the vertical g-load, Δn_y, depends on the vertical gust flow velocity, u, on velocity V, on the flight altitude and on the aircraft's weight; that is, $\Delta n_y = kVu$. The danger of the aircraft approaching the critical angles of attack and stalling occurs during flight in turbulence, because the increment in the angle of attack, $\Delta\alpha$, here is proportional to the ratio u/V. The relation $\Delta n_y = kVu$ shows that flight speed V must be reduced in order to reduce the g-load, Δn_y, at a vertical flow velocity, u; and $\Delta\alpha$ must be reduced, that is, flight speed V must be increased, in order to reduce the danger of the aircraft stalling. These contradictory requirements complicate the pilot's actions.

It must be kept in mind that the vertical air currents during flight at high altitudes cause the aircraft to approach extremely large angles of attack and the appearance of stalled conditions, and the formation of large (inadmissable) g-loads at low altitudes and high speeds. /62

The permissible flight altitude in slight and moderate turbulence does not change as a practical matter in comparison with the permissible flight altitude under normal conditions. The permissible flight altitude in severe and storm turbulence may differ by hundreds and thousands of meters from the permissible flight altitude under normal conditions, which presents a threat to flight safety.

The vertical currents may change direction in sections of thunder cloud cover.

When an aircraft enters an ascending current, it is thrown upward abruptly (up to 500-2000 m). The g-load here may exceed that permissible, and wing stall may occur; a tendency to dive appears because of an increase in lift on the horizontal tail; and yawing with regard to course and loss of control are possible.

The g-loads become negative when an aircraft enters a descending current; the aircraft has a tendency to pitch-up; and it loses altitude (by 600-1000 m).

Turbulence may lead to the engine shutting itself down during flight, especially at high altitudes, where the engine is more sensitive to change in

air flow. The air flow decreases, and engine surge and the engine shutting itself down occur in the zone of vertical currents as a result of the oblique entry of air into the engine. G-loads at a frequency of 4-5 Hz may occur in turbulence, which are difficult for the pilot to endure, because the natural oscillation frequencies of the human body, at which the upper and lower parts of the body begin to oscillate opposite in phase, correspond to this range.

Chapter 2

Primary Zones Having Complex Natural-Climatic Conditions /63

By natural-climatic conditions which affect the operation of aviation materiel, we mean the climate, the soil, and the animal and plant kingdoms.

It is customary to call climate the set of atmospheric conditions characteristic of each geographical region on the earth, which changes within certain limits from year to year, but changes very little from one period of many years to another. Climate is determined by the supply and consumption of solar energy, which depend on latitude; atmospheric air circulation, that is, the system of air currents bringing heat (cold) and moisture; and the vertical exchange of heat (cold) and moisture in the atmosphere. Climate is characterized by certain statistical conclusions from meteorological observations conducted in a certain region over a number of years, the mean, as well as the extreme (maximum and minimum), values of the observed parameters being important for use.

The geography of climates (climatology), which studies the distribution of climatic conditions on the earth's surface, provides the following classification of climatic zones (belts) in each hemisphere:

the equatorial zone;
the tropical zone;
the temperate zone;
the transpolar zone.

These zones are characterized by certain ranges of temperature values, precipitation, humidity, and other meteorological parameters.

However, in view of the fact that this work considers natural-climatic conditions as applied to the operation and storage of aviation materiel, it is desirable to classify them as follows: the transpolar zone, the temperate zone, the zone of dry steppes, semideserts, and deserts, and the zone of humid tropics and subtropics. /66

The proposed division is quite conditional. Thus, the zone of dry steppes, semideserts and deserts includes regions as different in terms of geography as the transpolar region, Tibet and the Sahara. What they have in common are a

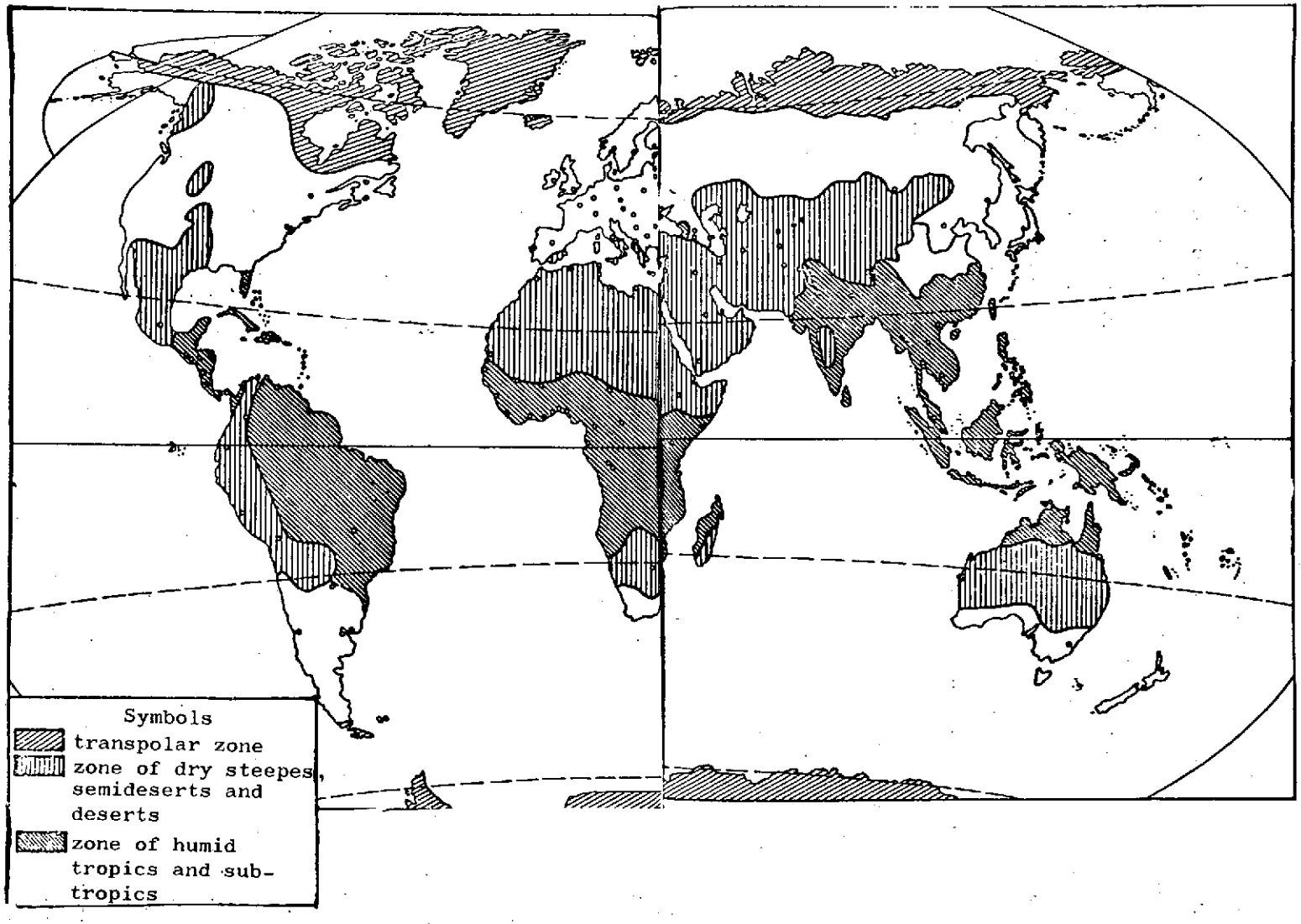

Figure 29. Map of climatic zones.

sharply continental climate, high temperatures, increased dustiness and salinity, a small amount of precipitation and a considerable diurnal variation in temperature. The map presented in Figure 29 visually shows the arrangement of the climatic zones on the earth's surface. It should be kept in mind that certain factors characteristic of the indicated zones also may affect regions which are not included in these zones according to the accepted classification. Thus, hard frosts are characteristic of Transbaikal, as well as the polar zone, and monsoons affect the climate of coastal areas, as well as that of tropical regions, and so forth.

The proposed classification of zones permits more purposefully considering the effect of natural-climatic conditions on the operation of aviation materiel, and at the same time makes it possible to apply the recommendations set forth below with regard to the operation of aviation materiel in geographical regions which have similar conditions in some respect to that in which it is based.

Soil conditions have a considerable effect on the operation of aviation materiel, especially when working at airfields with unpaved runways, taxiways and parks.

A brief definition of the most common soils is given, therefore, in the descriptions of the zones.

The animal and plant kingdom, which in normal conditions does not usually have a great effect on the maintenance and operation of aviation materiel, becomes one of the important factors making the use of aviation materiel difficult in conditions of a humid tropical climate.

The main natural-climatic conditions of the transpolar zone, the zone of dry /67
steppes, semideserts and deserts, and the zone of humid tropics and subtropics are considered below.

Transpolar Zone

The special features of the transpolar climate are a short, cold summer and a prolonged winter. Winds and snowstorms of great force are characteristic of this climatic zone. This zone should be divided into two subzones: humid and dry.

The first, the humid subzone, is characterized by the fact that it has an open sea surface throughout the entire year. Low temperatures are combined with

extremely high humidity in winter because of this. Even comparatively slight frosts under these conditions are hard for the personnel to endure.

The specific features of the humid subzone are the following.

High relative air humidity (varies from 85 to 95% during the year, average - 88%). The diurnal variations in relative humidity in winter are negligible, and reach 15-20% in summer.

The low position of the sun above the horizon in summer causes a deficiency in the annual amount of heat.

A large consumption of heat for the thawing of snow and ice.

Continual cooling of the air during the polar night.

The almost complete absence of diurnal variations in temperature (except for variations caused by the movements of cold or warm fronts).

Average temperatures: February - minus 20-22°C; July - plus 5-6°C. The average temperature is positive (and that is very low) for only four months a year. Possible amplitude of variations in temperature: annual - about 70°C, monthly - up to 45°C. The extreme negative temperature is -46°C, and the extreme positive temperature is +34°C. The average annual temperature is -6.4°C.

High relative humidity leads to the formation of cloud cover, fog and precipitation. Aureoles and "screens" form over luminaries under these conditions. /68

The cloud cover in the humid subzone is quite considerable. Table 5 gives its scale readings by months.

TABLE 5

Months	1	2	3	4	5	6	7	8	9	10	11	12
Cloud cover (scale reading)	6,2	6,1	5,7	6,9	7,9	7,7	7,2	8,2	8	8,2	7,9	7

Average annaual cloud cover is equal to 7.3.

Precipitation falls mainly in the form of snow. Table 6 gives the number of days with precipitation by months.

TABLE 6

Months	1	2	3	4	5	6	7	8	9	10	11	12
Snow	17	13	19	15	11	7	1	—	5	15	19	19
Rain	—	—	—	2	5	13	18	12	20	13	3	1

A peculiarity of the precipitation is its degree of fineness, drizzle and tiny ice crystals, and also its high penetrating ability, which increases under the action of a wind of great force. The snow has a high density (up to 0.7 g/cm^3).

The total annual precipitation averages less than 300-500 mm, despite the fact that the number of days with precipitation is very great, 228. But the amount of snow on airfields which must be cleared away is extremely great, because the wind carries snow from the elevated areas, and depending on the location of the airfield it may correspond to an annual amount of precipitation of over 2000 m.

The relief of the terrain has an extremely great effect on the thickness of the snow cover. Even small local irregularities or individual objects (for example, a lighting equipment lantern) cause the formation of large-sized snow banks with a high degree of density. Snow accumulates in the form of lenses, trains, small banks and mounds in the most unexpected places, and the height of /69 the drifts often reaches 5-7 m (Figure 30). A strong wind at a low temperature compacts the snow, and permeates ("cements") it with hoarfrost needles. This makes it extremely difficult to clear away the snow.

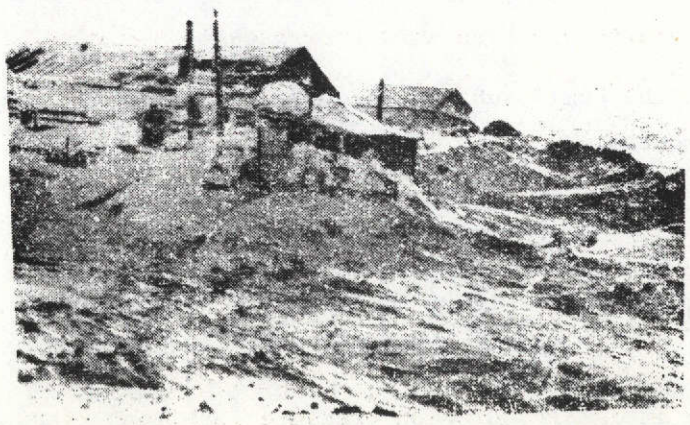

Figure 30. Snowdrifts near buildings near an airfield.

Fog forms, especially in summer, at low temperatures and high humidity caused by the proximity of the sea. Fog is noted 130 days a year on the average

in the polar humid subzone. Fog with visibility to 100 m often lasts throughout several days. Supercooled rain and thick fog settling on the ground form glazed frost.

There are winds of great force in this subzone throughout the entire year (see Table 7), blowing primarily from the cold ocean in summer and from the cold continent in winter. The number of calm days does not exceed 3% of the days in a year.

Polar aurorae are seen as many as 12-15 times a month and often are combined with magnetic storms. There are almost no thunderstorms.

TABLE 7 /70

Months	1	2	3	4	5	6	7	8	9	10	11	12
Average wind velocity [m/s]	8.8	8.1	8.6	8.2	7.6	6	5.5	6	7	8.4	9.7	9.5
Maximum wind velocity [m/s]	40	35	35	40	36	20	28	20	16	20	28	30
Days with snowstorms	18	16	14	9	3	-	-	-	-	5	12	15

Winter (October-April) lasts up to 6.5 months, and the polar night approximately 50 days. Cyclones passing through create low cloud cover and winds. A storm of drifting snow starts when the wind increases to 6-9 m/s; blowing snow with wind up to 12-15 m/s, where the visibility near the ground drops to 1 km; and a blizzard with wind up to 25 m/s, which can continue from several hours to 20 days. It should be noted that it is difficult to forecast snowstorms.

The formation of a special frost mist, which is invisible from the ground, but which makes visual landing approach difficult for the pilot due to the refraction of light rays, is characteristic of the winter period in the humid subzone. This mist forms in an area of high pressure in slight winds and a cloudless sky, and can be detected only from the air during weather reconnaissance.

The arrival of spring (May-June) is marked by an increase in the length of the light portion of the day (the polar day continues from the end of May until

the beginning of August), abrupt changes in the weather, and an increase in cloud cover and fog.

Summer (July-August) is characterized by a considerable amount of fog, low cloud cover and rainy precipitation. The ground is uncovered: peat-like soil or sand saturated with water.

TABLE 8

Subzone	Region	Air temperature [°C] Average coldest month	Air temperature [°C] Average warmest month	Air temperature [°C] absolute minimum	Air temperature [°C] absolute maximum	Air Humidity [%] average relative coldest month	Air Humidity [%] average relative warmest month	annual precipitation [mm]	Days with precipitation	Average wind speed [m/s] coldest month	Average wind speed [m/s] warmest month
First	Khibin	—12,9	13,6	—46	23	84	72	439	197	3,9	4,2
	Syktyvkara	—15,2	16,6	—45	34	84	69	500	207	5,5	4,5
Second	Dudinki	—29,5	12,0	—57	30	78	71	267	188	6,7	6,2
	Igarki	—29,6	14,4	—63	31	78	76	507	190	5,1	4,9
	Uelena	—22,7	10,5	—47	27	81	82	395	120	7,6	5,9

Autumn (September) is accompanied by a rapid decrease in natural illumination, the appearance of snowstorms, and a decrease in the amount of fog.

The second, the dry subzone, differs considerably from the first, mainly in winter, when the surface of the ocean is covered with ice. The average temperature of the warmest month is +8.6°C, and of the coldest month -30°C; the /72
absolute minimum temperature is -63°C. The average annual temperature is -12.3°C. There as as many as 42 clear days during the year (that is, twice as many as in the first subzone); 172 overcast days and 48 days with snowstorms.

The average annual relative humidity is considerably lower than in the first subzone, 70-75%. Therefore, there are no more than 42 foggy days a year. In winter the snow is fine but dry, and has a weak adherence (adhesion) to paint-and-varnish covering and metal.

Winds of great force are characteristic of the second subzone, as well as

the first. Wind velocity exceeds 15 m/s as many as 43 days a year. Cases have been noted when a snowstorm has continued for 14 days and more at a temperature of minus 38-40°C and wind velocity of 35-40 m/s. Wind velocity in gusts sometimes reaches 70 m/s.

Broken weather with low cloud cover and visibility of less than 1 km is characteristic of the dry subzone from the second half of May until the end of July, because the fog forming above the ocean surface free from ice is carried by the wind to the continent.

The amount of precipitation in the second subzone is negligible. Low humidity in winter reduces the possibility of icing of the strip. The other climatic factors do not differ in value as a practical matter from those considered in the first subzone.

Table 8 gives the climatic characteristics for individual regions of the transpolar zone of the U.S.S.R.

Zone of Dry Steppes, Semideserts and Deserts

The zone of dry steppes, semideserts and deserts (three subzones) is characterized by a sharply continental climate with a large amplitude of annual and diurnal variations in air temperature, high temperatures and little precipitation in summer, low temperatures and high air humidity in winter, salinity of the ground and ground waters, a high degree of dustiness of the air, strong winds, and a high level of solar radiation.

This work examines regions of Central Asia and the Near East as an example. Two periods are characteristic of these regions: hot and cold.

The hot period (May-October) is characterized by high air temperatures, low humidity and great dustiness. The temperature of the surface of the soil reaches +80°C, because the soil is heated by the almost vertical rays of the sun. The atmospheric layer is heated simultaneously to an altitude of 2500-3000 m and more. /73

The average monthly air temperatures remain in the range of +30°C, but the maximum temperatures reach +46 to +55°C. The air temperature in summer often is above +30°C even at night. Large diurnal variations in temperatures are noted at the beginning and end of the period (+2 to +5°C at night, +30 to +35°C in the day).

Heating of the air mass creates a low temperature gradient in an atmospheric

cross section. The zero isotherm is at an altitude of 5000-6000 m. Air temperature is equal to minus 45-50°C at an altitude of 12,000 m.

Air humidity beginning in June usually does not exceed 4-6%, as a result of which vegetation dies during this period. Strong winds are characteristic (25-30 m/s), the formation of which is linked with the passage of cold fronts. Dust, which is lifted by air currents to an altitude of up to 5000-6000 m, forms on loessial and sandy soils under these conditions (Figure 31). There may be no visibility for practical purposes at such times. In summer there are from 30 to 45 days with dust storms. Dust storms last from 0.5 to 12 hours and more. /75
Dust storms begin most often in the second half of the day and usually extend over a considerable area.

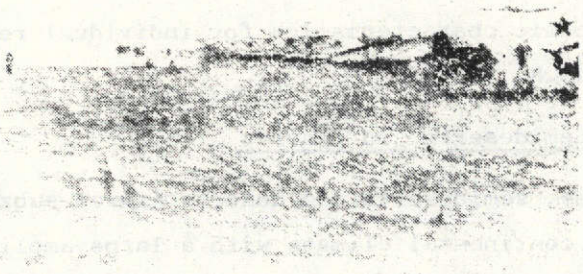

Figure 31. Dust on an airfield.

Slight winds cause storms of drifting dust. Dust haze after strong winds remains on a plain for 6-7 days, and considerably longer in terrain with mountains and valleys.

The occurrence of strong (over 12 m/s) winds of local origin also is characteristic of the zone of dry steppes, semideserts and deserts; their occurrence is caused by the diurnal temperature difference and the relief features of the terrain. Such winds occur primarily in the second half of the day and last for 1.5-2 hours.

The cold period (November-April) is characterized primarily by overcast weather with low cloud cover, precipitation and dense fog. The amount of precipitation in this period is quite large and depends greatly on the relief of the terrain. Relative humidity reaches 90-100%, but varies widely in the course of days, which causes abundant condensation of moisture on metal parts. Sharp variations in temperature also are characteristic of this period.

TABLE 9

Subzone	Region	Air temperature [°C]				Average relative air humidity [%]		annual precipitation [mm]	days per year with precipitation	Average wind velocity [m/s]	
		Average		absolute minimum	absolute maximum						
		coldest month	warmest month			coldest month	warmest month			coldest month	warmest month
Dry steppes	Volgograd	—9,6	24,2	—35	41	86	52	318	139	6,3	4,6
	Astrakhan'	—6,9	25,1	—42	41	86	62	175	97	6,6	4,8
Semi-deserts	Dushanbe	1,4	28,2	—27	42	81	37	611	90	1,5	1,5
	Tashkent	1,1	27,4	—30	42	71	41	367	78	1,4	1,3
Deserts	Krasnovodsk	2,4	28,9	—17	42	74	52	103	96	3,2	4,5
	Ashkhabad	0,6	30,4	—26	45	83	37	244	69	1,9	2,4
	Bayram-ali	0,6	29,8	—26	45	76	31	127	41	3,1	2,8
	Kerki	2,4	30,2	—22	45	75	30	164	44	3,2	2,4
	Termez	2,8	31,4	—21	48	79	34	133	42	2,6	2,8

Climate conditions differ in the southern latitudes of this zone (the Sahara, the Australian Desert, etc.) in that there are somewhat higher temperatures and no clearly defined cold period.

The mountainous regions of the Pamirs, Tibet and the Cordilleras may be included in the zone of dry steppes, semideserts and deserts.

Table 9 gives the climatic characteristics of individual regions of the different subzones.

Zone of Humid Tropics and Subtropics

Regions included in the zone of tropics and subtropics belong in most cases to the equatorial region and the equatorial monsoon region, which include vast areas of the earth. There are summer and winter monsoons.

Cold air from the north, where air pressure usually is higher, is carried to the south in winter in the monsoon regions of the northern hemisphere. This air, with very little moisture, becomes still drier when heated; therefore, compartively little precipitation falls here during the winter monsoon period. /76

The zone of tropics and subtropics is characterized in summer by low pressure, and winds take on a southerly direction, from regions of increased pressure located above the ocean. These winds carry equatorial air saturated with moisture. The hot and rainy weather characteristic of the summer monsoon sets in with their arrival.

Thus, there are two seasons: rainy (hot) and dry (cool).

Climatic conditions in the dry season (winter) correspond approximately to summer in temperate latitudes. This season lasts from November through May. The so-called intermediate period sets in, however, in certain regions of the earth (for example, in Viet Nam) from the end of January until the beginning of April. It is characterized by a sharp increase in air humidity, the falling of fine rain and the appearance of thick fog.

Air temperature in these regions reaches maximum in May; the sun is almost at zenith during the day; and the period of showers begins. The first gusts of the southern monsoon, which constantly intensify, are noted in May. The hot and rainy season with periodic high winds sets in from June through November. Sometimes there are typhoons. High humidity and high temperatures make this season difficult for people to endure.

Table 10 gives the indices of climatic conditions characteristic of the tropics.

TABLE 10

Months	1	2	3	4	5	6	7	8	9	10	11	12	Annual indices
Average temperature [°C]	18,4	19,9	21,1	24,7	27,9	30,0	29,3	29,3	27,6	25,1	22,6	20,9	24,8
Total precipitation [mm]	42	37	43	48	99	74	107	113	432	509	343	137	1991

The temperature gradient with increase in altitude is 4-5 degrees per 100 m. The absolute maximum temperature does not exceed +48°C; and the observed minimum temperature is +1°C.

Annual precipitation varies from 1000 to 6500 mm, 85% of it falling in the

summer monsoon period. As much as 900 mm of precipitation may fall in days.

The water, as a result of electric discharges, is saturated with nitrogen oxides, which increase its corrosive properties (up to 70 kg of nitric acid settles on 1 hectare in a year).

Cases of such large hail falling that it is dangerous for aircraft glazing /77
and skin are frequent. It is hurricanes (typhoons), however, that are the most dangerous for aviation materiel. They usually move in a narrow (30-150 km across) strip and have very low (740-743 mm and lower) atmospheric pressure in the center and a small radius, which creates exceptionally high pressure differentials. Winds occur at velocities exceeding 50 m/s as a result. Winds of such force easily tear down trees and destroy buildings and electric transmissions. The waves raised by them flood enormous coastal areas.

The only means of saving materiel under these conditions is redeploying it upon receiving a storm warning. Timely warning of the approach of a typhoon permits materiel to be evacuated and measures to be taken to save the personnel and preserve ground equipment. Hurricanes in the northern hemisphere are most frequently from July through November (as many as two or three a month in one region).

The diurnal amplitudes of variations in temperature in the zone of tropics and subtropics usually do not exceed 10°. The sky is almost always covered by clouds, because the average annual cloud cover exceeds 7. The thickness of the cloud cover varies from 6 to 8.5 during the year; however, the intensity of solar radiation (direct and scattered) is very great, up to 400 cal/cm^2, because the sun is high in the sky. The relative air humidity is extremely high and changes little during the year (from 77 to 91%).

Chapter 3

Special Features of Operating Aviation Materiel in Zones with Complex Natural-Climatic Conditions /78

Special Features of Operating Aircraft in the Transpolar Zone

The transpolar zone is characterized by a combination of low temperatures and high relative humidity and salinity of the air, as well as winds of great force and fine precipitation. These factors cause considerable difficulties in operating aviation materiel; however, standard aviation materiel may be used successfully in the Far North.

A number of the special features of the technical operation of aircraft in the Far North are considered below.

Special Operating Features of the Airframe and Aircraft Systems. Accomplishment of the primary operating task, that of ensuring the high reliability and constant readiness of aviation materiel for use under the conditions of the Far North, is linked closely with protecting the aircraft from the entry of fine snow into its compartments, wells, and vent and drain holes. The aircraft may lose combat capability for a long period if this cannot be accomplished for any reasons. This fact is evidence again of how important it is to ensure aircraft sealing. A great quantity of compressed air and considerable labor expenses are required to remove snow from the aircraft, while an aircraft which is well protected from snowdrifts can be put into the air after the usual inspection.

Low temperatures and increased humidity may lead to the occurrence of a /80 number of characteristic failures. Thus, the suppressor grids in the engine are covered with ice, and cases of the turbine and compressor blades freezing to their casings are frequent. This makes it necessary to turn the rotor manually before starting the engine. Moisture entering the fuel freezes at low temperatures, and the ice which forms clogs the filters. Therefore, the filter elements must be taken out and dried during the preflight preparation. The frontal edges of the aircraft subassemblies in flight and on the ground often are subject to icing and freezing (Figure 32a, b, c), which requires the use of various ice-removing means (chemical, thermal and mechanical).

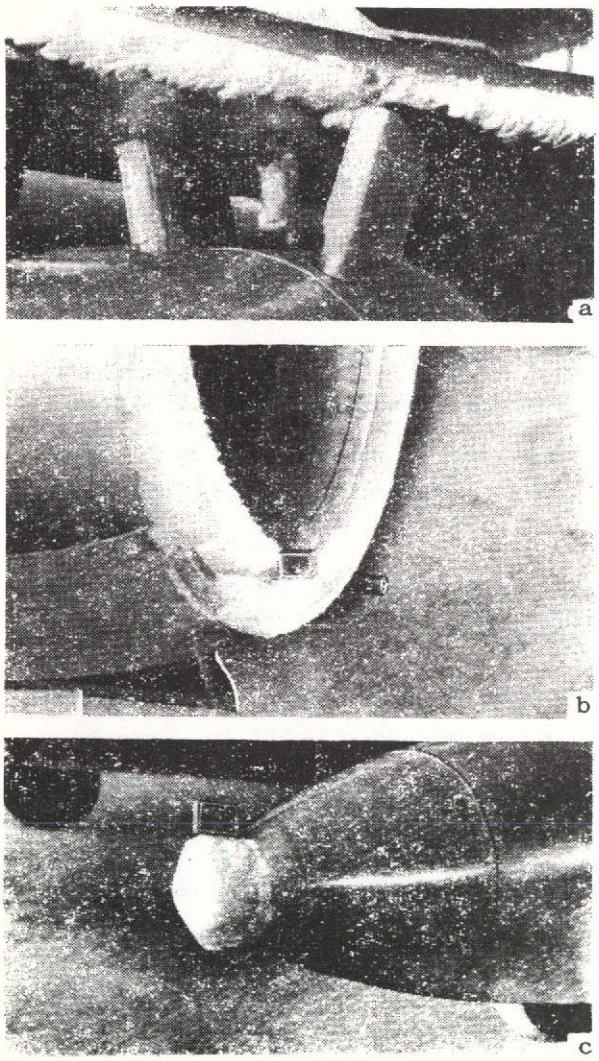

Figure 32. Iced and frozen frontal edges of aircraft subassemblies: a - wing leading edge; b - air intake; c - leading sections of auxiliary tank.

Leakage of the working fluid and destruction of the diaphragm of the hydraulic accumulators is observed in hydraulic system subassemblies due to loss of elasticity by the sealings and rubber parts at low temperatures. Operation of the turning mechanisms of the leading leg, the aerial drives and other subassemblies is disrupted (immediately after starting) as a result of thickening of the working fluid. Disruption of the work of these mechanisms ceases after the system warms up.

Leakage of the working fluid in the joints of the service lines and hydraulic systems sometimes is noted due to the temperature shrinkage of elements of the nipple connections in the pipelines and the tips of the flexible hoses at low temperatures.

The pistons in the air cylinders of the recharger, those in the landing light swivel system and those in the electro-pneumatic valves freeze, as do the filter elements, due to the precipitation of moisture from the air in the pneumatic systems.

Control system components are quite vulnerable at low temperatures. Locking of the control rods because of freezing of the cranks or hermetic lead seals and loss of elasticity by the fabric of the control surface aerodynamic balance also are characteristic failures for the climatic zone under consideration.

Low temperatures complicate the operation of the landing gear. Because of

the insufficient cold-resistance of rubber during hard frosts, the wheel retains its shape as changed by deflection for some time and loses its round shape, which may cause tire failure during taxiing or take-off, and additional loads are /81
created on the aircraft and equipment when the aircraft moves along the ground. Pressure decreases in the shock absorber due to a reduction in air temperature. This increases shock absorber sag and makes its working pattern worse. Deposits of snow and ice on the landing gear locks cause their failures. The entry of snow into the wheel brake gaps and the electro-pneumatic valve exhaust ports of the anti-skidding automatic equipment system reduces the working reliability of the braking system. The operation of the sealings deteriorates, which leads to leakage of the working fluid from the shock absorber. The undercarriage leg must be fitted with special covers, the condition of the braking system and the locks must be watched, and the landing gear must have warm air blown on it before departure in order to prevent these occurrences.

Cases of the cabin glass breaking have been noted as a result of the abrupt drop in temperatures when the electric defroster is turned on. It is advisable to install a rheostat in the circuits or to blow warm air on the glass beforehand in order to turn on the heating gradually.

It is unnecessary to start turbocoolers in the cabin pressurization system in many types of aircraft in the transpolar region. The turbocoolers in these cases are disconnected or dismantled.

Protective covers must be put on the engine immediately upon the aircraft's return from a flight to prevent uneven cooling of its parts. It is very important that the blades be inspected carefully to see whether they have been damaged by pieces of ice.

When fueling aircraft, measures must be taken to prevent snow and water from getting into the fuel. Alcohol and acetone may be used so the caps do not freeze to the fillers (rub the caps and fillers), and they may be heated, observing the rules of fire safety.

Special Features of Operating Electrical, Radio and Instrument Equipment. The joint effect of low temperatures and high relative ambient air humidity, as well as the fine precipitation in the transpolar climatic zone, makes the operation of electrical, radio and instrument equipment extremely complicated. Thus, /82

3-5 times more time than usual is required for warming up the radio and radar set before beginning work. Low temperatures sharply reduce the mechanical, as well as electrical, characteristics of many widely used materials, which leads to failures and change in equipment parameters. Increased attentiveness is therefore required when operating it. Labor expenses for equipment repair and operation increase considerably.

Increased air humidity also creates many difficulties. Icing of contacts, increased force to set mechanisms in motion, sweating and freezing of instrument glasses, breakdown of the choke and certain other failures are characteristic of operation in the first subzone of the transpolar zone.

The entry of fine precipitation into the equipment blocks through the slots and vent holes requires great consumption of compressed air for its removal. Short circuiting, loss in performance, freezing of movable mechanical units and other failures are inevitable if it is not removed. The number of equipment failures may increase sharply also because of the extremely low efficiency of rubber-and-metal shock absorbers at a negative temperature.

The most radical means of ensuring the reliability of equipment operation are the use of materials with stable mechanical and electrical parameters and sealing of the equipment compartments and individual blocks. Naturally, this may be accomplished to the full extent only in a specially designed aircraft. Nevertheless, the use of usual materials and additional parts and devices for sealing subassemblies and their heating may increase equipment reliability considerably and reduce its operating effort in any aircraft.

Simple devices for aircraft to be operated in the North are manufactured easily by the efforts of the personnel of service units and repair shops. These are, first of all, sets of plugs, corks and covers, which ensure the airtightness of compartments containing equipment, as well as placing felt and oilskin seals under the hatch edges, greasing the slots with a sealant, and stopping up extra vent holes and perforations, which protects the blocks and instruments from moisture entering them. Individual hermetic covers often can be made for the blocks. If the usual relays, switches and connectors cannot be replaced by sealed ones, they should be insulated: wound with insulating tape, coated with a sealant, and so forth. An illumination light should be installed in the box where these relays are placed, which can be turned on regardless of

/83

whether the given system is working or not. Experience has shown that the installation of such lights, for example, in engine starting panels yields excellent results; the heat given off by the light hinders the formation of an ice crust on the contacts.

Attention should be paid to the additional insulation from moisture of the negative terminals, because large sections of the electrical systems often break down as a result of their icing.

"Slack" in the sections between their attachment points must be ensured to prevent breaking of the wires with decrease in temperature. It is unacceptable to attach wire with vinyl chloride clamps, because they break in a frost and their hard fragments may jam the control wire elements. Binder twine should be used if there are no cold-resistant plastic clamps.

The condition of the limit switches, especially those in undercarriage wells, must be watched carefully when equipment is operated. The limit switches often fail to work when they are iced and clogged with snow.

Cases of the destruction of the rubber fan blades have been noted. Non-heat-resistant rubber blades should be replaced by metal ones. The cabin must be warmed up with ground-based heaters before flight to prevent freezing of the glasses or instrument failure. The cover placed on the pitot-static tube usually is laminated. This protects the receiving channels from being penetrated by moisture.

The necessity to maintain a positive temperature in the battery container /84
causes many difficulties. Special devices for warming up the battery are used widely at present.

It is advisable to replace the sealing elements in the radar waveguides before converting to winter operation, because their shrinkage at low temperatures may cause depressurization of the waveguides. Plastics and rubber glued on metal may be destroyed due to the difference in the linear expansion ratios.

Protecting the antennas from damage causes great difficulties, especially when removing snow from the aircraft, as well as during a blizzard (from impacts of the covers).

Special Features of Ground Equipment. The special conditions of the technical operation of aviation materiel in high latitudes brought about some changes in the

structure of devices making up ground equipment, as well as in their assembly.

Protecting the aircraft and its equipment from snow, rain and rime ice is a necessary condition for its operation in the transpolar region. Covers are used for this purpose. But the standard covers are of low strength, easily let in precipitation and usually freeze to the skin. Therefore, they must be made as follows for the first transpolar subzone:

ropes should be sewn on the edges of the covers to increase strength under wind action;

the covers should be two-layer to ensure airtightness, and the lower layer should be made of balloon cloth;

the covers should cover the aircraft surface completely;

the covers should be strengthened by sewing on tape in squares (or by winding cord or textropic tape around the aircraft on top of the cover when there is a storm warning);

soft cloth bolsters must be sewn to the inner surface of the covers so they do not freeze to the skin;

sealed covers must be made for the pitot-static tube, the landing gear, and so forth.

Standard covers may be used for the second transpolar subzone, but they must be strengthened additionally with tape.

The standard set of protective covers shold be supplemented considerably. 285
All drain holes, louvres, vent pipes, flaps and wells must be tightly closed without fail. Even the undercarriage wells and the deceleration flap wells should have special caps. The poor fitting of protective covers and caps entails extremely labor-consuming work with regard to removing snow that is densely frozen together from the interior chambers. The protective covers should be joined together in several pieces by cord or a strap to prevent taking off with a cover accidentally left on.

In view of the frequency and sudden storms, the personnel at an airfield should always be ready for actions with regard to a storm alert in the event a blizzard occurs. A detailed plan of actions upon the onset of a blizzard should be worked out and the personnel informed of it at each airfield in conformity with local conditions. All aircraft and ground equipment should be reliably secured. The wheels should be covered, and brake shoes must be

placed under the wheels on both sides. It should be kept in mind that it is impossible for practical purposes to perform any work in terms of reinforcing covers, aircraft and ground equipment during a blizzard. The serviceability of tie-down equipment must be inspected and checked systematically. Light and transport aircraft with large side surfaces and small loads on the wing should be tied down especially carefully.

The use of a tent with a rigid, cabriolet-type framework, which must be tightly fitted along the contour of the aircraft lines, is recommended in hatches where equipment is installed to facilitate work during a snowfall.

The mats used for work in the transpolar zone should be thicker than usual, because it is impossible to sit or lie down on the ground even in summer.

The removal of snow from an aircraft's compartments and hatches requires a large expenditure of compressed air. The expenditure of compressed air may be reduced considerably by installing a simple nozzle on the end of the hose from the bottle.

Compressed air, soft scrapers and besoms usually are used for the removal of snow and rime ice from an aircraft's surface. The aircraft may be sprayed with ethylene glycol or antifreeze in special cases when it is necessary to get the aircraft into the air quickly. The glazing and the hatches must be protected from these liquids when this is done. /86

All special vehicles, including fire trucks, should be installed on an undercarriage with increased passability (however, even in this case, it is often necessary to resort to towing aircraft with a caterpillar tractor).

In view of the difficulties of moving special vehicles along a snowbound airfield, the airfield should be equipped with centralized fueling facilities and the cables from the electrical units should be lengthened.

It is necessary to work under artificial light during the polar night. Therefore, it is advisable to equip the airfield with remote columns with voltage input to which heating and lighting equipment may be connected. Lighting parks by floodlights yields good results. All service vehicles should be equipped with heating facilities for the cabins, and especially the glasses, and devices which facilitate starting in frost.

Special Operating Features of Airfields. Operating conditions of airfields

in the first transpolar subzone are considerably more complicated than in the temperate climate zone. As has been said, fine snow under conditions of high relative humidity and with winds of great force easily forms drifts and mounds with a high degree of solidity. Powerful equipment is needed to ensure aircraft operation under such conditions: graders, rotary snow blowers, bulldozers, and so forth.

Snow must be cleared away continually during a blizzard, or else the height of the drifts may reach 5-7 m, and a great deal of time will be required to put the airfield back into service. However, it is difficult to use equipment when visibility is less than 500 m, because the danger of colliding with parked aircraft increases.

The amount of snow cleared away from an airfield in the first transpolar subzone in winter is enormous. As much as 2,000,000 m^3 of snow has to be cleared away from an airfield with an area of 80 hectares. The snow is especially thick on downhill slopes and in depressions. Small irregularities lead to the formation of snow trains and mounds. A drift 1-2 m high occurs for each light delimiting the runway. Sunken lights must be installed, especially since lights of the usual design are damaged easily when the strip is closed. /87

There should not be buildings, vehicles or anything else for a distance of 100-150 m from the strip. Ground equipment should be deployed with regard to the prevailing wind direction.

Drifts also form in the parks around the aircraft, often covering them to the fin tips. Clearing the parks is labor-consuming, does not lend itself to mechanization, and requires exceptional care.

The snow removed from the runway must be leveled and smoothed, or else new snow drifts form around the banks.

Storms of drifting snow occur almost continually; therefore, snow carried from elevated areas must be cleared away even when there is no snow falling.

Snowplows operate under very demanding conditions, because the snow in the transpolar region has a high density and, in addition, freezes to the runway. Therefore, only powerful snowplows are used in the transpolar region.

The snow cover on an airfield is of unequal thickness; therefore, snow is cleared away by individual sectors.

Snow is not removed from a metal runway, because the metal surface is quickly put out of service with the operation of bulldozers and graders. It is advisable to make an unpaved runway beside it for winter operation of the airfield.

It is necessary to know the prevailing wind direction well and to place the cleared snow in accordance with it. The optimum snow removal schedule for each airfield must be worked out, taking into consideration the wind direction and the special features of the given airfield.

This schedule should indicate the places designated for dumping snow. The snow removal equipment must be consolidated into units. Each unit should include a rotary snow blower, graders, bulldozers, and smoothers.

The thickness of the snow cover must be considered in the concrete snow removal plans, and the task for the day assigned in accordance with it. /88

Taxiways become snowbound to a considerably greater degree than a runway. The removal of snow from them is made difficult by the fact that the work front is considerably narrower on them. High banks form along their sides, the width of which should be increased to the maximum, smoothing them down carefully.

The strip in front of the parks, on which aviation materiel is moved, is cleared before the snow is removed from aircraft or helicopter parks. Then each park is cleared.

A considerable amount of fuel is consumed during snow removal, because the snowplow engines have no mufflers, for practical purposes (because of starting difficulties). 24-hour duty of one unit of the snow removal equipment must be ensured at airfields throughout the winter.

Specialized airfield vehicles and tractors are required for work under transpolar conditions. Adapting standard vehicles is labor-consuming and unprofitable.

Fighting snowdrifts is considerably easier in the second subzone of the transpolar zone than in the first. Little snow is retained on the runway because of low air humidity, and the drifts are comparatively less dense. Snow can be cleared away quite easily with the usual means, as a result. When removing snow under second subzone conditions, it must be distributed evenly along the

side, without permitting the formation of a bank.

There are at present no radical means of preventing icing of an artificial runway. Considerable labor expenses are required to maintain the operating readiness of such a runway under icing conditions.

It is not advisable to use common salt to destroy an ice cover on a runway or taxiway surface, because it has a considerable destructive effect on the aircraft structure and on the concrete runway surface. A sufficiently economical and effective substance which could be used on a large scale to destroy an ice film has not been suggested at present, although experimental work is being conducted in this direction. Thus, British airports have conducted tests of sprayer units on the undercarriage of a five-ton truck (the unit consisted of a tank for 1500 l of the liquid chemical, a pumping unit and the sprayer device with a range of up to 16 m). The de-icing liquid, the chemical used in these units, consisted of isopropanol, which quickly destroys ice, and a mixture of less volatile glycols, which act more slowly on ice and ensure the steady treatment of the runway. The chemical, used in a mixture with an equal volume of water, had no harmful effect on the aircraft's structural elements, its equipment, tires, or the runway and taxiway surface. A similar unit, in which the liqiud "Depatinol HS" was used, was tested at Zurich Airport. Despite the good effectiveness of these chemicals, this work has not gone beyond isolated tests, obviously, due to its high cost. /89

Runways and taxiways at English airfields often are sprinkled with granite particles with an individual diameter of no more than 4.7 mm.

Vehicles fitted with wire brushes and heat engines on which turbojets which have completed their flying life have been mounted are used primarily at present for destroying an ice crust. However, the runway surface is destroyed rather quickly when both types of vehicles are used. In addition, it is necessary to see that fragments of the concrete surface and the metal wire from the brushes are removed from the airfield.

24-hour operation of the heat engines on runways and taxiways often has to be organized at airfields in immediate proximity to the sea, which leads to considerable fuel expenditures.

It was found to be advisable in some regions to leave a protective layer of snow on the runways and taxiways, which would ice less intensively and when

necessary could be removed with the usual powered graders.

It is advisable to build ice airfields in the transpolar zone, a characteristic distinction of which is the abundance of water surfaces (sea, river, lake) covered with a layer of ice for most of the year. /90

The ice surface, prepared properly, may be used as a runway, since it has a high degree of stability and does not require large labor expenditures for treating it. Thus, according to American data, 160 men with five light bulldozers built a runway 1500 m long and 100 m wide in 46 hours of non-stop work. C-130 aircraft completed more than 50 landings in three days without causing any damage to the strip. Ice airfields have proved themselves completely in practice in the Soviet "Severnyy polyus" [North Pole] drifting stations and in Antarctica.

It is advisable to pour warm water on the finished strip, in view of the fact that pot-holes and ice fragments form when the ice runway is leveled.

It is believed that ice runways may be preserved during warmer periods by applying special coatings to them. An aqueous solution of a foaming mixture, which does not have to be removed from the runway later, is recommended for use as one of these protective coatings. Runways may be maintained in serviceable condition throughout the year in transpolar conditions with its help. The foaming mixture includes an aqueous solution of albuminous materials and a stabilizer, carboxymethyl cellulose and a gelling agent (aluminum acetate). A durable foam, which is stable against variations in temperature and which provides a degree of expansion up to 7, is obtained as a result of blowing compressed air through this mixture. A 50 mm thick layer of such foam reduces the intensity of ice thawing by an average of from 120 to 6 cm^3/h.

Peat crumbs or sawdust may be used to prevent an ice (snow) runway from thawing.

The basic requirement which must be satisfied by the section chosen for an ice airfield is the thickness of the ice and the good condition of the ice surface. The necessary ice thickness in centimeters may be determined from the following empirical formulas (with a double safety margin):

for fresh ice

$$h_{req}=\kappa\sqrt{G}; \tag{3.1}$$

for sea ice

$$h_{req} = a(20\sqrt{G} - 10), \tag{3.2}$$

where

G is the take-off weight of the aircraft in tons;

k is a coefficient which takes into account the ambient air temperature: k = 16 when t < -10°C and k = 22 when t > -10°C;

a = 12 and is a coefficient which takes into account the possible displacement of ice-floes due to friction upon deceleration of the aircraft.

The necessary ice thickness sufficient for safe take-offs and landings should be increased in comparison to the calculated thickness by twice in summer and by one and a half times in fall and spring.

The actual ice thickness in centimeters is determined in terms of given measurements from the formula

$$h_{act} = h_1 + 0{,}5h_2, \tag{3.3}$$

where

h_1 is the thickness of the transparent ice layer;

h_2 is the thickness of the cloudy ice layer,

or by a calculation from the formula

$$h_{act} = 2{,}56C\sqrt{Nt_m},$$

where

C is a coefficient which depends on local conditions (river - 0.5; transpolar region - 0.76);

N is the number of days since ice formation;

t_m is the mean air tempeature for the calculated period [°C].

Aircraft are positioned at greater distances than usual on ice airfields.

When positioning aviation materiel on an ice airfield, the special features of severe weather, which may complicate the work of the pilot and technical personnel considerably, should always be considered. The following should be included first of all among such special features:

strong wings from different directions, as a result of which aviation materiel, personnel quarters, and means of communication are snowbound, which makes delivery of supplies more difficult;

the appearance of cracks and separations, which may cause the replacement of runways, taxiways and aircraft parking areas;

abrupt changes in air temperature, especially in spring and fall, which /92
affect the strength of the ice.

All this requires that the personnel be ready constantly for immediate actions to save facilities and to secure or move aircraft to safe parking areas during storm alerts.

Aircraft parking areas, in addition, must be checked and leveled systematically, especially on sea ice, in order to discover a deformation of the ice surface in time. This requirement is caused by the properties of sea ice, which can be compressed under static loads due to its porous structure and because it has less strength than fresh-water ice. The compression process for sea ice is more intensive during the first 2-3 hours after the load is applied.

Special features of ensuring the normal work of personnel. The work of personnel under transpolar conditions is made more difficult by low temperatures, increased air humidity, strong winds and heavy snowfalls, as well as poor illumination. The quality of technical clothing, above all, is important in these conditions. Jackets should be lined with artificial fur, lengthened, fitted closely at the waist, and have hoods. Artificial fur is sufficiently dense, gets less wet and dries better than beaver lamb. Trousers should have a high waist and loops for fastening boot tops. Boots should be fur-lined, because boots with fur on the outside quickly fill up with snow and are difficult to dry. Shoes should have a warm fur lining and an especially strong sole, adapted for walking on stony ground. Special attention should be given to making all clothing waterproof. It is advisable to use leather helmets with long ear-flaps and head pads in transpolar climatic conditions, because the normal caps with ear-flaps are easily blown off by the wind and do not protect the forehead and the back of the head.

Floodlights must be installed in parking areas to increase illumination during the polar night. It is advisable to expose the personnel to quartz lamps

periodically. The rest quarters for the personnel should have blinds for darkening during the polar day, so as not to disturb the sleeping regime. /93

Special Features of Operating Aircraft in Semidesert and Desert Terrain

The zone of dry steppes, semideserts and deserts is characterized by the long-term effects of increased temperatures, by a sharp temperature change in the course of days, by the extreme dustiness of the air, and by the salinity of the air, soil and water. These factors complicate the work of the personnel and cause increased wear on aviation materiel (Figures 33 and 34).

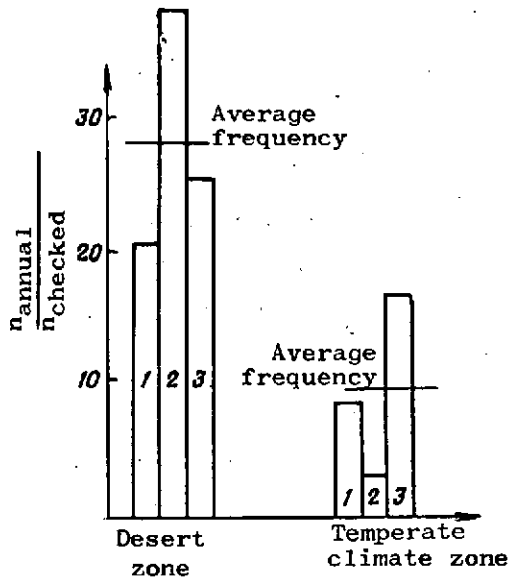

Figure 33. Relative frequency distribution of the rejection of worn-out bearings in the turbocompressor shaft of engines operated in the desert zone and in the temperate climate zone: 1 - front roller bearings; 2 - center ball bearings; 3 - rear roller bearings.

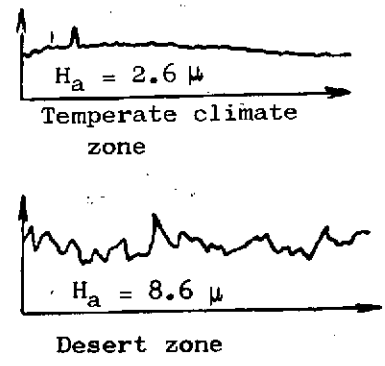

Figure 34. Profilograms of the engine compressor air intake surface after expiration of its service life in the desert zone and in the temperate climate zone.

Some special features of operating aviation materiel in desert and semi-desert terrain are considered below. /94

Special operating features of the airframe and aircraft structures. An abrupt temperature change and the action of solar rays and dust cause cracking, loss of elasticity and lag from the skin of the paint-and-varnish coating on the external surface. Figure 35 shows the primary aircraft skin areas where the paint-and-varnish coating is destroyed most intensively. The varnish film is preserved considerably better on the undersurfaces of the wing and fuselage,

which are protected from the effect of direct solar rays. Restoring a coating with high quality is difficult in summer in a desert or semidesert, because the air is constantly saturated with dust. In those areas where there are no closed premises, therefore, large sections of aircraft surfaces must be painted in fall and winter (but when the temperature is positive).

The following may be recommended to preserve a paint-and-varnish coating: cover aircraft carefully and (to a lesser degree) put them under awnings. /95

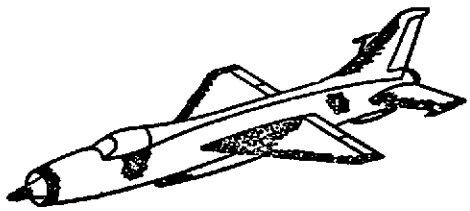

Figure 35. Aircraft skin areas where the paint-and-varnish coating is destroyed especially quickly (shaded).

The outer plating of the skin panels often is destroyed due to abrasive wear from the action of sand and pebbles during take-off and landing, especially on the wing leading edge and the fuselage nose cone.

The cabin glazing is most subject to destruction under dry steppe, desert and semidesert conditions. Microcracks ("silver"), which form as a result of the crystallization of acrylate under the action of solar rays, usually are found in the glazing of aircraft that have been operated for more than three years. A large number of notches and scratches appear on a plexiglas surface, which reduces its transparency. The reason for their occurrence is the abrasive action of dust and sand.

Finally, the cabin glazing often acquires a yellowish tint, apparently under the action of ultraviolet rays. The requirement to keep the canopy glazing under a cover therefore acquires special importance. The cover must be clean, because sand particles accumulating on the inner surface of the fabric may damage the plexiglas surface.

Preventing wear of the friction surfaces is an important part of the work in ensuring the reliability of materiel. This work involves in the first place taking protective measures to prevent the entry of dust into the subassemblies. The use of covers, plugs and protective covers similar to those examined previously has a great effect. The undocking units require especially careful protection. An effective means of fighting wear is the systematic

(as often as possible) removal of dust from the friction surfaces.

It should be kept in mind that wear of parts under dry steppe, semidesert and desert conditions also is intensified considerably by the fact that the lubricant is partially burned out of the gaps under the action of high temperatures. The mixture formed when dust and sand get into the lubricant has high abrasive action. Therefore, the timely removal of dirty lubricant and the putting in of fresh lubricant is of paramount importance for increasing the reliability of aviation materiel. The times for performing these operations indicated in the /96
regulations should be adjusted considerably under concrete conditions.

The fixed size of the gaps in the joints must be checked more often, because parts wear out much more quickly under dry steppe, semidesert and desert conditions than under normal conditions. It is thought that the use of closed and obturator bearings facilitates the operation of aircraft and helicopters considerably.

A considerable quantity of dust may get into the hydraulic systems when insufficient care is taken in the process of open filling. In addition, dust adhering to the surface of the actuation cylinder rods, as well as from the air, penetrates the system through the hydraulic tank pressurization system.

Deep notches and scratches on the precision coupling surfaces, and destruction of the sealings and packings, is discovered when the hydraulic units are disassembled. This fact again confirms that fueling facilities must be maintained in good order, fueling rules must be observed, the cleanliness of the liquid in the system must be checked systematically, and it must be replaced ahead of time when necessary. Fueling must be carried out when it is not windy, observing maximum precautions and using dust-proof gear.

The friction surfaces of the undercarriage units operate under difficult conditions in desert and semidesert terrain, as evidenced by the large number of dents, deep scratches, and so forth; as well as by the rapid increase in play during operation in the points where the shock absorber and undercarriage legs are attached by bolts and pins, in the levered wheel suspension points and Y-shaped lugs. The rods, pistons and cylinders of the hydraulic cylinder-gear retraction jacks also wear out quickly.

The landing gear tires operate under still more difficult conditions in the desert and semidesert. Their service life in the summer months may be reduced

substantially. This shows that the primary factor affecting their reliability is temperature. Correct operation of tires in desert and semidesert terrain /97
results in increasing their service life substantially. Thus the pressure, which increases in the tires with increase in temperature, must be reduced (with an increase in air temperature of 15°C, the pressure in the tires increases by 12-13%). But in view of the fact that the variations in temperature in the course of days are very great, the danger arises of putting an aircraft in the air with tire pressure greater or less than that required with regard to technical conditions.

It also is difficult to ensure the reliable operation of the brakes in the zone of dry steppes, semideserts and deserts, because their cooling at high ambient air temperatures is reduced sharply, especially when flights are repeated at short intervals. Water may not always be used to cool brake drums, because, first, a sharp temperature drop results, which may cause the wheel material to crack; secondly, the water in this zone often contains a large quantity of salts and is the cause of energetic corrosion of parts, especially those made of magnesium alloys.

Fighting salinity is in general an extremely difficult matter. Every day the aircraft must be cleaned, the areas where salt acts must be wiped with a rag, joints must be lubricated and the protective paint-and-varnish coating must be touched up. Salt penetrating closed and almost inaccessible compartments often causes the formation of such centers of corrosion that the units must be changed long before their prescribed service life has expired. The most radical protection measure under these conditions is maximum sealing of compartments.

Great care is necessary when using salty water to wash aircraft, and it must be removed from surfaces immediately and completely. Even the briefest contact between aircraft parts and units and such water may lead to aircraft breakdown, and often may make it inadvisable even to make repairs.

The process of testing subassemblies and systems on stands is made more complicated. When subassemblies are removed in windy weather aircraft compartments are contaminated and dust gets into systems. All precautions must be observed, therefore, when removing them. The removed subassemblies should be carried to /98
laboratory rooms in a tightly closed container.

Time must be set aside specially for removing dust from aircraft compartments after each dust storm or storm of drifting dust.

Sharp variations in temperature cause change in engine working parameters. The air by-pass bands in some types of turbojet engines must be readjusted to prevent surge. Cases of the propelling nozzle opening spontaneously during take-off have been noted.

Clogging of the choke packets and metering jets of the fuel metering equipment with hard particles, and the accumulation of dust in the burners and combustion chambers also may affect engine stability and temperature conditions. Coagulation of fine impurities in the filters, which reduces their effectiveness considerably, often is observed.

As was mentioned in Chapter 1, engine starting from a turbine starter is complicated with an increase in air temperature. To prevent this phenomenon, readjustment of the turbine starter in terms of revolutions per minutes, using their maximum permissible values, may be practiced. Fuel consumption increases then, as well as the pressure ahead of the turbine, as a result of which the power of the starter is increased considerably. If this measure proves insufficient, it is advisable to start the engine with open cowling, which substantially reduces the maximum temperature in the turbine starter and the pressure losses at the inlet in the turbine starter compressor.

For aircraft with piston engines, the air temperature in the landing area of the airfield should be considered to prevent overheating of the cylinder heads during landing approach.

Special operating features of aircraft equipment. When operating electrical equipment, special attention must be paid to the level and concentration of the electrolyte in the batteries, because the evaporation of water in the zone of steppes, semideserts and deserts is accelerated substantially; insulation resistance must be measured systematically and the condition of the electrical bundles checked visually (there must be no drying and cracking); the rubber caps on electrical equipment components which have dried out and lost elasticity /99 under the effect of high temperatures and ozone must be changed in good time; the adjustment of the relay devices must be watched, because it may be upset due to dust getting between the armature and the pole; and measures must be taken to

seal the relay housing (rubbing with adhesive, gluing with sticky tape, and so forth).

Attention also must be given to the serviceability of limit switches, which often fail because they become clogged with dust when they are insufficiently sealed.

Instrument equipment requires systematic checking of the following in conditions of the zone of dry steppes, semideserts and deserts:

the condition of the oxygen hoses and rubberized hoses in the pitot-static tube system, because their service life is reduced in the conditions of the zone of dry steppes, semideserts and deserts under the action of the dry air, ozone and high temperature;

the elasticity of rubber oxygen-demand regulator valves and those of the continuous oxygen trigger equipment;

the elasticity and intactness of the cabin pressure control membranes and the safety valves;

the damping device of the electrical turn indicator (there should be no sand or dust in the damper cylinder);

the pitot-static tube system (there should be no dust in the lines or instruments);

the rubber-and-metal shock absorbers, which should be elastic and should not have cracks.

Routine servicing effort for instrument equipment may increase by 8-10% in this zone.

The operation of electronic equipment is complicated because of the necessity to check the adjustment of the radar circuits when there is a sharp change in air temperature and humidity, as well as when converting to winter or summer operation; to check the condition of the pulse motor ratchet cams (there should be no wear), the radar antenna drives and other electromechanical devices; /100 to check the condition of the ventilation and cooling devices (they should be in good working order; and to remove dust from the blocks regularly.

The routine servicing effort for electronic equipment may be increased by 2-4% due to special operating features.

Special features of ground-based equipment. The standard set of ground-based equipment is not always sufficient to ensure the normal operation of aviation materiel in the desert and semidesert zone. This set should be supplemented with equipment intended to prevent dust from getting into aircraft compartments, to remove dust already in compartments, to decrease the surface heating of the aircraft and its cabin, and to increase aircraft passability.

It is advisable to manufacture and use protective covers, similar to those described earlier, to prevent dust from entering aircraft compartments.

Vacuum cleaners or purging with compressed air may be used to remove dust already in compartments. It is advisable in both cases to use special attachments permitting the removal of dust from inaccessible areas. The first method is effective, but its use is limited by the small power of vacuum cleaners. The second method cannot always be used, because while compressed air removes dust as well, it pushes it at the same time into equipment blocks and other inaccessible spaces. A combination of both methods is used in practice.

In view of the great dustiness of the air, any operations associated with disassembling units and instruments must be performed only in rooms protected from dust.

Various awnings and canopies should be built and used to prevent aircraft surfaces, interior compartments and cabins from heating. Figures 36, 37 and 38 show how temperature changes in the fuselage, in the cargo cabin and in the fuel in the aircraft's tanks, respectively, and the ambient air during the day in the summer months. Figure 39 shows how air temperature changes in the aircraft cabin and in the fuel in the tanks during the course of the day. Awnings and canopies protect the aircraft from the action of direct solar rays, and heating of aircraft structures and their interior compartments is reduced somewhat as a result. Aircraft covers sometimes are moistened for this purpose. Table 11 gives the air temperature in an aircraft cabin when protective awnings are used and covers are moistened. /102

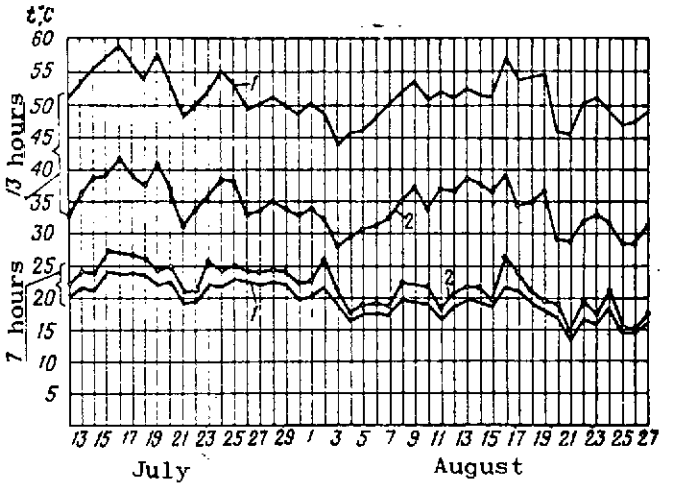

Figure 36. Temperature change in the daytime in the summer months: 1 - aircraft fuselage skin; 2 - ambient air.

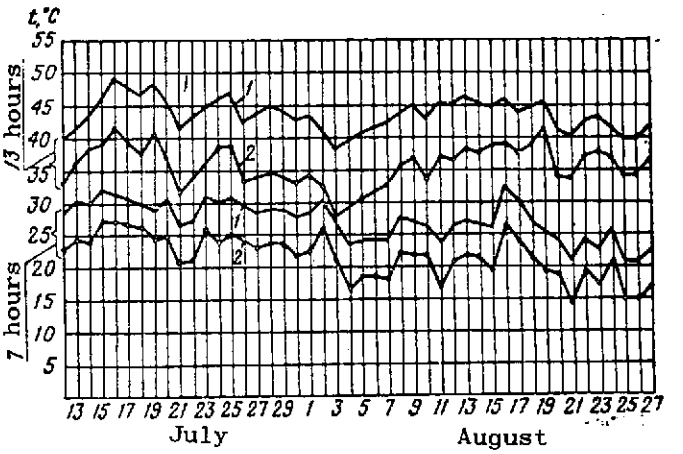

Figure 37. Temperature change in the summer months: 1 - aircraft cargo cabin; 2 - ambient air.

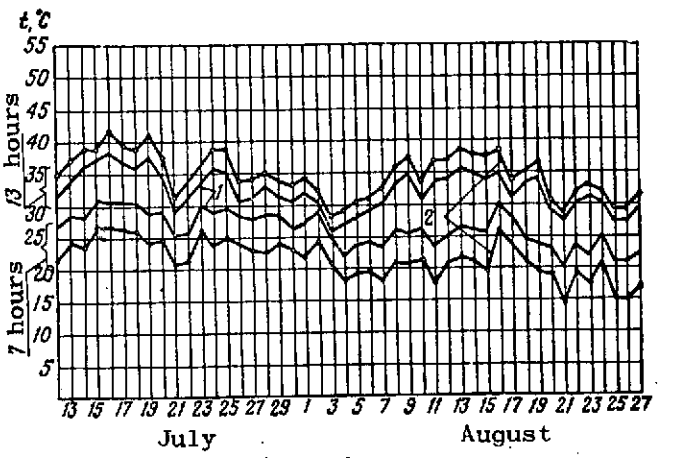

Figure 38. Temperature change in the summer months: 1 - fuel in aircraft tanks; 2 - ambient air.

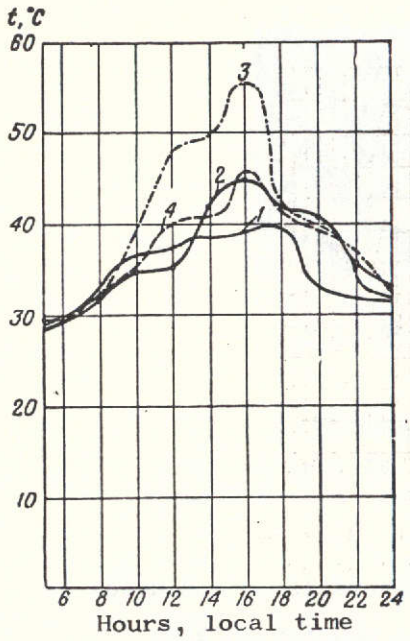

Figure 39. Temperature change during the course of days: 1 - outside air; 2 - fuel in aircraft tanks; 3 - cabin of uncovered aircraft; 4 - cabin of covered aircraft.

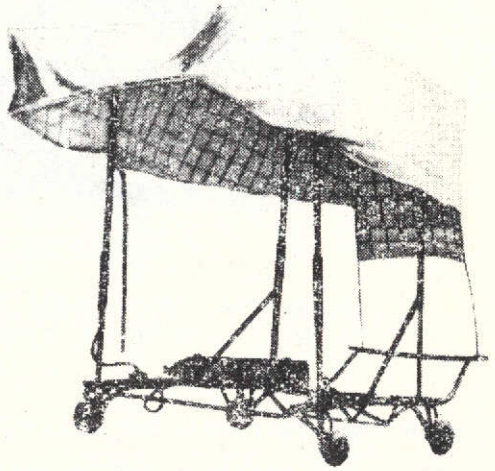

Figure 40. Portable awning for protecting the aircraft from solar rays.

TABLE 11

Time of measurements (local) [h]	Outside air temperature [°C]	Cabin Temperature [°C]			
		Uncovered aircraft	Aircraft with awning over cabin	Aircraft covered with moistened cover	Aircraft covered with moistened cover and with awning over cabin
10	24	23	21	20	20
12	27	40	26	25	24
14	29	41	28	25	24
16	30	41	28	25	24

Figures 40 and 41 show examples of the structure of an awning and of the special tent used for working in the zone of dry steppes, semideserts and deserts. /103

Dry sand and sodden soil make it difficult to tow aircraft with high-pressure tires. Large loads act on the aircraft structure here, and, in addition, the towing vehicle may not have enough tractive effort. Therefore, detachable devices /104

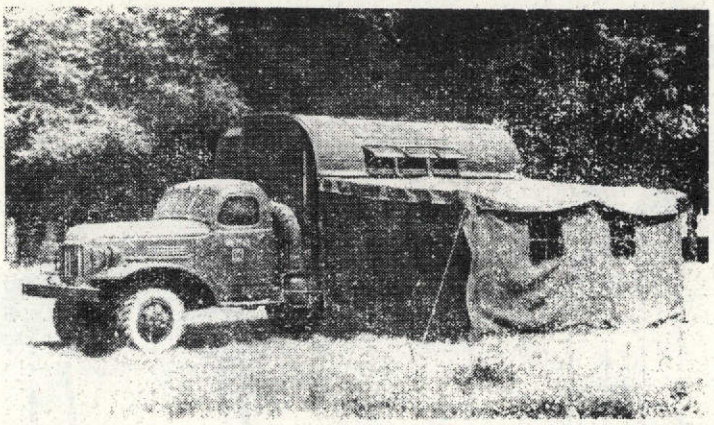

Figure 41. Detachable tent by a special vehicle for working under dusty conditions on units removed from an aircraft.

which increase the aircraft's supporting surface are manufactured and used: a bogie (bicycle type) with two wheels on the cross-piece mounted on each undercarriage leg; the mounting of a second wheel on the additional axis of the main undercarriage leg. Little time is required for the mounting and removal of these devices, and aircraft passability becomes equal to that of a tractor when they are used.

Thus, the primary operating features in the zone under consideration may be formulated briefly as follows:

all possible measures for sealing aircraft compartments and hatches should be taken, including improvised means, to prevent dust from getting into them;

ground operations must be planned with regard to the probability of dust storms occurring; therefore, disassembling work should be reduced to a minimum and performed so that the removed parts may be installed quickly and the aircraft may be covered; /105

any work involving the disassembly of parts and units during a dust storm should be prohibited;

all premises intended for the disassembly of units and subassemblies should be as sealed as possible to prevent dust from getting into them;

measures must be taken for protection against the action of direct solar rays on aviation materiel;

aircraft and motor vehicle transport should move along the airfield in conformity with the wind direction, which prevents dust from being deposited on aircraft.

Special features of operating airfields. Airfield soils in the zone of dry steppes, semideserts and deserts in terms of physical and mechanical composition are usually loess-like dusty loams, often high in water-soluble salts (up to 13% salt, sometimes as much as 35%). 60-80% of the total soil mass is dusty and clay fractions with a small amount of gravel and sand particles. Such soils quickly become sodden when precipitation falls and easily form fine dust in the dry season. Operation of aircraft with any flight weight from unpaved airfields is ensured theoretically in the dry season. However, in practice the operation of aircraft from such airfields is made difficult, because a large quantity of dust is formed due to the complete absence of sod-forming vegetation. The layer of dust reaches 10-15 cm. The dust raised by aircraft does not settle for a long time, and this makes the take-off and landing of other aircraft difficult. Figure 42, for example, shows a section of an airfield during taxiing: clouds of dust literally cover the entire horizon. Treatment of unpaved runways and taxiways with a mixture of highly tarry oil and gravel decreases the amount of dust and increases their water-resistance. Such a coating is comparatively inexpensive and ensures year-round operation of unpaved airfields.

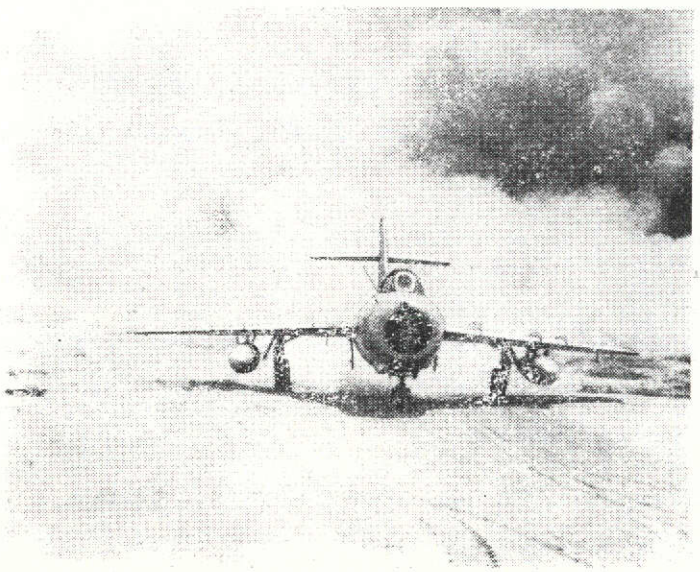

Figure 42. Section of an airfield when an aircraft is taxiing (dust covers the horizon).

A perspective method of quickly reinforcing an unpaved runway surface is the spraying of special compounds, including epoxide, polyester and urethan /106

resins, fire cement and other materials. A meratial consisting of commercial chlorine-containing polyester resin, granulated boric acid, antimony trioxide, fiber glass, and methyl ethyl ketone as a catalyst has been mentioned in the foreign press as an example of such a coating. This mixture forms such a strong coating that it withstands several take-offs and landings by a vertical take-off and landing aircraft, which creates a reaction jet with a temperature of 1650°C and a pressure of 17.5 kgf/cm^2. This mixture hardens between 2 and 40°C in 15 minutes on any soil.

A drawback of the material is the comparatively high cost of its ingredients. Nevertheless, it is quite possible to use it to create take-off and landing areas for vertical take-off and landing aircraft, engine run-up areas, parks and starting and stopping areas on unpaved runways. /107

The service properties of paved runways deteriorate under conditions of high temperatures and dust storms: the filling material of expansion joints melts on cement and concrete pavements; the soil escapes from under metal pavements, causing deformation of the plates and breaking of the slots and hooks; soil-and-oil coatings become soft, tracks form in them, and local failures of the pavement occur. Salty water ruins all types of artificial surfaces.

Labor expenses to maintain airfields in condition suitable for use increase under the climatic conditions of the zone of dry steppes, semideserts and deserts.

Unpaved airfields are out of service for 20-60 days in the rainy season, depending on the location.

The soil and climate features of this zone make it necessary to remove snow completely from artificial, as well as unpaved, runways. Water also must be removed from hard-surface runways.

Metal runways are inconvenient, because when perforated plates (with holes) are used dust is raised during take-off and landing; when solid plates (without holes) are used it is more difficult for the aircraft to maintain its direction of motion, "skidding" occurs, and the aircraft rolls beyond the limits of the runway.

The service life of unpaved runways may be lengthened considerably if the

ground surface is compacted before the season of bad roads. The systematic and timely removal of snow and water also furthers this. In order to lengthen the service life of a paved runway, snow and water must be removed from it, expansion joints must be repaired in good time, and pot holes must be eliminated by filling with ground and replacing plates.

Special features of the work of personnel. Experience shows that most natives of the middle latitudes take a long time to become acclimatized and do not withstand semidesert and desert climate well. This must be taken into consideration when determining the load on them. At the same time, flight and technical operation demands an enormous expenditure of strength by all personnel. /108

Heat has an exhausting effect on the personnel, and their working capacity is reduced considerably. The metal surfaces of aircraft, airfield equipment and instruments heat up to temperatures of 70-80°C and higher. Touching them may cause a burn to the skin. It is difficult to work on maintenance under conditions of a strong gusty wind on a dusty airfield, and practically impossible during dust storms.

The temperature in the working area and in aircraft cabins must be reduced first of all in order to maintain the greatest working capacity of the personnel.

A necessary condition for constructing buildings in the zone of dry steppes, semideserts and deserts is the correct selection of the type of construction and the appropriate orientation of the windows of the working areas. Table 12 shows the air temperature in various working areas in relation to the outside air temperature, and Figure 43 shows how the temperature changes in the course of a day in areas with different orientations with respect to solar rays. /109

It should be kept in mind that a reduction in temperature by even 3-4 degrees has a significant psychological and physiological effect. This is reinforced still more if green areas can be created near parks and service areas.

The most drastic method of reducing temperature is the installation of air conditioners. If there are not enough of them, an effective reduction in temperature may be achieved by the following means:

1. The use of awnings, umbrellas and covers. It has been said above that simple devices, such as awnings, umbrellas and covers, which protect the

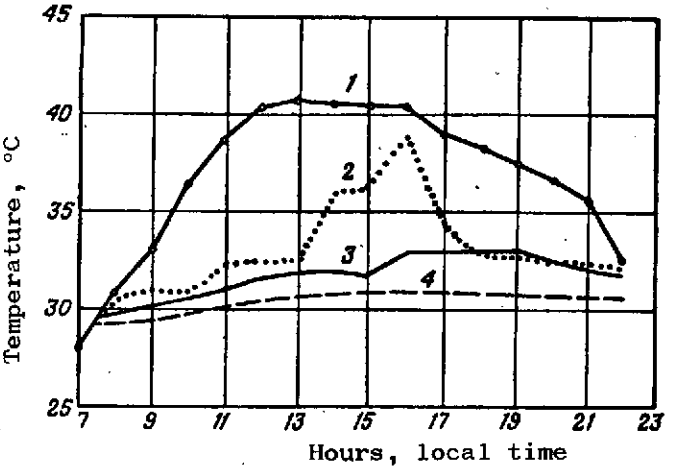

Figure 43. Diurnal change in outside air temperature and air temperature in areas with different orientation with respect to solar rays: 1 - outside air; 2 - air in room with windows facing west; 3 - air in room with windows facing east; 4 - air in room with windows facing north.

TABLE 12

Type of Room	Temperature [°C]					
	at 1000 hours		at 1700 hours		at 2300 hours	
	outside air	room	outside air	room	outside air	room
Hangar	37	33	40	36	30	30
Brick building	37	35	40	37	30	32
Prefabricated building	37	35	40	38	30	33
Slate-roofed shed; body of special vehicle	37	43	40	52	30	36

paint, glazing and the rubber and plastic parts of an aircraft from the action of direct solar rays, considerably increase their service life. At the same time, they reduce the temperature in the cabin and in the aircraft servicing area noticeably. Only a few minutes are required to remove them, while the umbrella-awning shown in Figure 44 can be removed practically instantaneously by one man and may be used to protect the pilot in the aircraft cabin from the sun.

2. Moistening the covers and the aircraft's skin surfaces with water. This

is a very effective means, which reduces cabin temperature by 2-6°C. However, it cannot be used everywhere, because, first, it sharply increases water consumption /110 (a single moistening of the nose cover of a light aircraft requires about 50 liters of water, and it evaporates in 15-20 minutes), and there is not enough of it in many desert and semidesert areas; secondly, it increases the danger of corrosive damage to the aircraft by salts dissolved in the water.

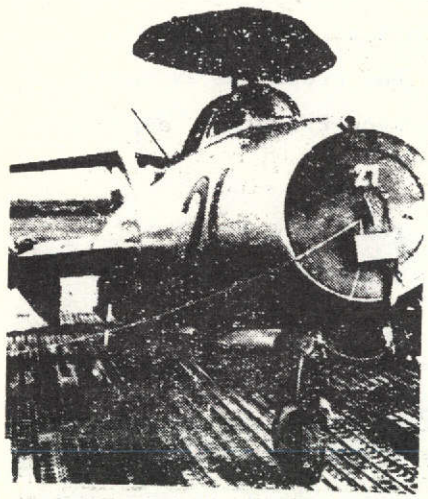

Figure 44. Umbrella-awning to protect the pilot in the aircraft cabin from direct solar rays.

3. The use of fans and blowing with compressed air. This method creates mainly a psychological effect. In addition, it has a major defect, in that it creates local supercooling of perspiring skin, which leads to catching colds.

4. The use of portable air conditioners. The most effective method of maintaining normal temperature conditions in aircraft cabins is the use of portable ground-based air conditioners, which provide a constant supply of fresh, cooled air and ventilate the cabin.

The AKV-30/120 air conditioner is used at present for heavy and medium transport aircraft (Tu-104, Il-18, An-10, Il-14, Li-2 and others). The conditioner's cooling capacity is as much as 30,000 kcal/h, and its air capacity is 3500-4200 m^3/h. When the ambient air temperature is as high as +45°C, the temperature of the cooled air entering the cabin is +13°C. /111

These same air conditioners are used in winter for heating aircraft cabins, full-pressure suits and ventilated suits by supplying heated air.

There are also similar devices for light aircraft.

The type IP-300 portable engine heater may be used to accomplish simple ventilation of the cabins of transport aircraft by purging them with the ambient air. However, the effectiveness of cabin cooling using their ventilation is small when the ambient air temperature is high.

Special Features of Operating Aircraft in Humid Tropical Conditions

A characteristic feature of the zone of humid tropics is the joint action on aviation materiel of high temperature, increased relative humidity and biological factors, which create exceptional difficulties for its operation.

The experience of World War II, as well as the American experience in South Vietnam and the daily experience of operating materiel of all types in the tropics, shows that materials and structures manufactured without consideration for the special features of a tropical climate fall into disrepair extremely quickly, often even during transportation and storage. The press has reported, for example, that the equipment losses during transport from France to Central Africa reached 60%, and those to South America 36%.

Only the use of so-called "tropicalized" equipment reduces losses to acceptable values. "Tropicalization" is carried out in three main directions:

preventing excess humidification;

preventing the development of mold fungi and bacteria, as well as the action of other representatives of the vegetable and animal world;

preventing the development of corrosion due to the action of moisture, heat and biological factors.

Excess humidification is extremely characteristic for a tropical climate with its frequent showers, fogs and abundant dew, which falls morning and evening. /112 The thickness of the layer of moisture falling in the form of dew may reach 3 mm, while several hundred millimeters of precipitation may fall in several hours during showers. Condensed moisture evaporates slowly in closed compartments, forming a kind of "steam bath." The principal means of combating moisture in the tropics are sealing, frequent ventilation, and, however paradoxical, local heating.

Sealing may be used on a limited scale in the process of operating aviation material, because even a small leakage, permitting so-called "breathing", that is, the exit and entry of air into a sealed volume with change in temperature, may cause damage by furthering the accumulation of moisture in this volume. However, the use of hermetically sealed tanks, plastic sealed covers and "cocoons" in storage conditions is an extremely effective means of preserving aircraft subassemblies and parts and is used widely.

Frequent ventilation, despite the effort involved, is absolutely necessary. But it must be remembered here that under conditions of frequency and abundant precipitation, the slightest carelessness may lead to inundating the aircraft's interior compartments with water.

Purging with hot dry air from heaters often must be used, or heating elements must be fastened inside the compartments and individual blocks to remove moisture forming in them as a result of the condensation of dew from the air or falling during a shower.

Fighting bacteria, yeast fungi, and fungous mold is an exceptionally complex task, because these organisms are extremely varied and extremely resistant to different methods. As many as 15,000 types of fungi are known. Some of them penetrate into materials, as well as forming surface colonies. Microorganisms develop most intensively at a temperature of from +7 to +40°C, and die only when heated to above 100°C. The destruction of materials occurs under the action of enzymes, albuminous substances secreted by the microorganisms and by-products of their vital activities (citric, carbonic, oxalic and other acids). /113

Moreover, equipment failures often are caused by the very presence of the colonies (loss of transparency of glazing and optics, seizing of certain mechanisms, and so forth).

In order to prevent the formation of fungus colonies, materials should be selected which are not a nutrient medium for organisms, and substances toxic to microorganisms (fungicides) should be used. Quite a few types of fungicides are known at present (salicylanide, albichtol, phenylphenol with thiuram, naphtol, pentachlorophenolates of copper, sodium and zinc, and others). They are used to treat materials, as well as to fumigate interior volumes and rooms.

Some materials which are widely used in the temperate zone (for example, castor oil, linseed oil, phenolic resins and plastics based on them, cellulose, cotton cloth, varnished cloth, leather, animal glues, laminated insulation, and wood) are a nutrient medium for many organisms in the tropics.

Polystyrene, polyethylene, ceramics, glass, fiber glass, polymethacrylate, polyvinyl chloride, nylon and natural silk usually are not damaged by microorganisms.

Other representatives of animate nature also are difficult to fight. The

most widespread representative of fauna in the tropics is termites. They live in colonies and feed on wood and other organic materials. Termites can gnaw through concrete and brick to get to these materials; they make holes in metals by secreting formic acid. Termites destroy wooden structures and various wooden articles very quickly, while the outer shell remains undamaged. This prevents discovering the damage in time and taking appropriate measures.

Beetles, moths, wood borer worms and ants have as destructive an effect on wood, felt, and woolen and leather articles. Red ants can destroy all rubber articles and wire insulation on an aircraft in several hours. Cockroaches and other insects often cause short circuiting when they get into equipment, obstruct the pitot-static lines when they get into them and cause the failure of /114 flight instruments. In addition, they damage the insulation, hoses, pipes and so forth.

Rodents (mice, rats, etc.) also put parts made of organic materials out of service quickly, above all the insulation on electrical wires. They build nests in aircraft compartments.

Nets with 1 mm holes (clearance) are used as protective means against insects, and with 1 cm holes against animals, in addition to chemicals. Local varieties of wood (eucalyptus, sandal-wood, teak, bamboo) suffer less damage by mold and insects; however, even they should be painted with oil paints with 4% chlorodane added, and they should be soaked in sel'kur first. At present, however, an effective chemical means of protection against mold and insects has not been developed; therefore, constant checking of aviation materiel and replacement of structural elements that have failed is necessary under humid tropical conditions.

Cases of collision with birds are frequent in all latitudes, but they are most frequent in the tropics, especially at low altitudes, when visibility is poor, at night, and at twilight.

Effective methods of combating collisions have not been developed, despite great scientific-research work. All possible means of frightening birds away from airfield areas, where collision with aircraft taking off and landing is most likely, should be used. Such means include: destruction of breeding sites, destruction of the food base (edible vegetation, dumps, etc.) and shelter areas of birds, pyrotechnics, limitating the operating time of lighting equipment which attracts birds, and playing tape recordings imitating danger signals.

It should be noted, however, that the effectiveness of the last method decreases considerably with time, because, first, the birds get used to the recorded danger signals; secondly, bird calls recorded in another area do not always frighten local birds of the same species and have no effect at all on birds of another species.

Specially-equipped motor vehicles and special repeaters placed along the runway are used to frighten birds at English airfields in the tropics. Each air- /115
port has tape recordings of the call of several kinds of gulls, lapwings, jackdaws and starlings. Depending on what kind of bird appears on the airfield, the flight control officer turns on the necessary tape.

Birds flying at comparatively high altitudes, especially in flocks, show up well on radar screens. Birds cutting a glide path are seen on the precision approach radar as low-velocity blips. The flight control officer can change the aircraft's altitude and flight course in case of danger.

The TsIATIM-201, -202, -203, and -208 lubricants have shown satisfactory anticorrosion properties in tropical conditions. Use of the TsIATIM-221 lubricant is recommended for antifriction bearings; and of the GOI-54 lubricant for corrosion-proofing of precision mechanisms and for their antifriction lubrication.

When parts and subassemblies are stored for a long period of time, they must be corrosion-proofed and packed carefully (preferably sealed). The use of inhibitor packing means yields good results.

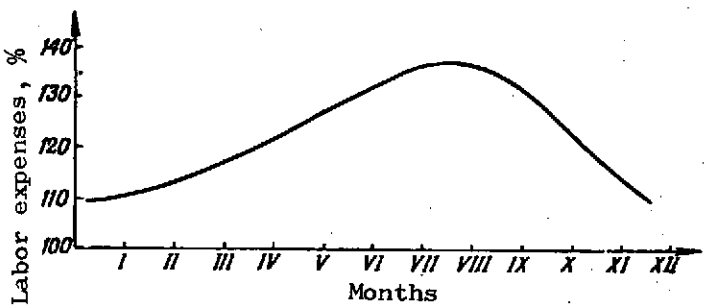

Figure 45. Change in labor expenses for preparing an aircraft for departure according to months of the year (in tropical conditions).

It should be kept in mind that when the humidity of the packing container boards is over 12% corrosion of the contents begins, and the resistance of paint-and-varnish coatings in the tropics is reduced on the average by a factor of three in comparison to their resistance in the temperature latitudes. The

circumstances listed considerably increase labor expenses for servicing aircraft, especially in summer. Figure 45 shows how labor expenses for preparing an aircraft for departure increase (labor expenses in the temperate zone in summer are taken as 100%). See Chapter 5 for more detail on combating corrosion. /116

Special features of operating aircraft equipment. When operating aircraft equipment in humid tropical conditions, it should be kept in mind that the service life of insulation depends on the outside air temperature and is reduced on the average by a factor of one and a half for every 10° it increases. The capacity of variable capacitors changes at the same time. Insulator discharge voltage is 90% when the relative humidity is 90%, and 50-70% of its rated value when the humidity is 100%. A selenium rectifier serves for 100,000 hours at 40°C, and for 100 hours at 100°C. Even these examples show that tropical conditions are extremely unfavorable for the reliable operation of aircraft equipment.

The most frequently encountered equipment failure is insulation break-down. A conductive bridge forms on the insulator surface, sparking occurs, and the insulation material chars. The insulators fail when this process is repeated many times. Plastic laminates, especially laminated insulation, quickly develop cracks on the ends and separate. Binders based on phenolic resins and varnishes based on linseed oil soften under the action of climatic and biological factors, and release organic acids which cause corrosion. Electrolysis reactions occur in direct current circuits under the action of humidity, which intensively destroy contacts, insulation and current-carrying elements. Therefore, reserve batteries should be sent to the tropics in drycharged form.

The intensity of ultraviolet rays increases sharply in the equatorial regions. This causes accelerated ageing of insulation materials, industrial-rubber and other products of macromolecular compounds.

Many insulation materials, including natural rubber, are destroyed especially quickly under the action of mold. Insulation resistance is greatly reduced then. Capron parts and fabrics suffer heavy destruction as a result of the combined action of light, heat, and moisture. The most effective way to protect equipment /117 is to fill the terminal blocks with epoxide (polyester) resin. The draining-off of the condensate which forms must be provided for in order to prevent the accumulation of moisture in the casings; and their inner surfaces must be painted

a dull, dark color to increase heat emission. Vacuum tubes should be mounted horizontally to increase their reliability. This reduces their temperature by almost 20°. Baseless tube structure is more reliable, because the base material is destroyed quickly. The action of moisture on selenium rectifiers causes an increase in reverse current (unforming) so they, like other semiconductor components, need regular ventilation. The installation of electric incandescent lamps in assemblies gives good results.

It is particularly difficult to keep radar from overheating, so it is advisable to install air conditioners in the operator shacks and radar compartments. This increases radar reliability and improves operator working conditions.

Meters must be completely sealed. It is advisable to calibrate meters again in situ, or else their readings may be highly erroneous.

Meter defects most typical of the tropics are destruction of plastic casings, bases, and parts, loss of shape and defacing of scale markings, mold on precision couplings and glass, and pitot-static lines becoming jammed and overgrown with mold.

Special features of the work of personnel. The humid tropics and subtropics occupy about 20% of the earth's land surface. They are often thickly-populated areas (Indonesia, Vietnam, India, etc.); however, acclimatization to the tropics presents certain difficulties for natives of the temperature latitudes. This is associated with the special features of the joint action of high temperatures and humidity on the human body. Body temperature should be between 36.2 and 37°C, regardless of external conditions, for normal vital activities.

Excess heat may be liberated by convection, perspiration evaporation, heat /118
conduction and heat radiation. The intensity of these processes depends on the temperature gradient and the saturation pressure of water vapor between the surface of the skin and the ambient air. Air temperature in the tropics comparatively rarely exceeds 35°C, which is substantially lower than values usually observed in the desert zone; nevertheless, it is considerably more difficult to endure a tropical climate. The graph given in Figure 46 shows that the temperature gradient in the daytime decreases considerably. Convection, although at a decreased rate, is maintained.

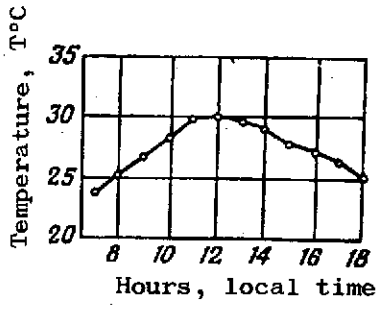

Figure 46. Change in outside air temperature in the tropical zone in relation to time of day.

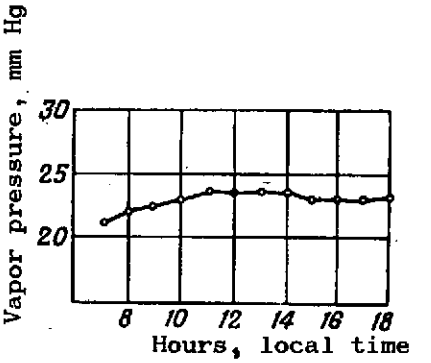

Figure 47. Change in the partial pressure of water vapor in the tropical zone in relation to time of day.

The intensity of perspiration evaporation depends on the partial pressure differential of the water vapor (Figure 47). The partial pressure has sufficient value for the evaporation of perspiration, but it is substantially lower than in the desert zone. It should be noted also that oxygen exchange in the alveoli of the lungs becomes more difficult with increased humidity. The joint action of all these factors explains the generally unfavorable action of a humid tropical climate on the human body, which becomes especially noticeable when performing intensive physical labor. The abundant vegetation increases humidity. This makes the work of the personnel still more difficult. Figure 48 /119 shows the change in relative humidity in the tropical zone in relation to the time of day.

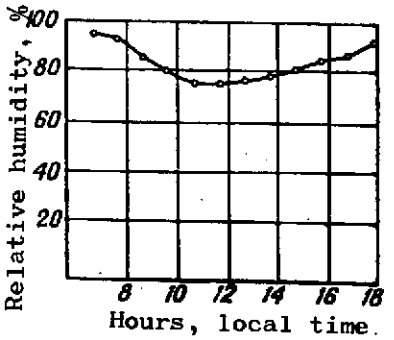

Figure 48. Change in relative air humidity in the tropical zone in relation to time of day.

Solar radiation does not reach extremely high values, because the sky is comparatively seldom cloudless, but it is unsafe to remain under direct solar rays for a prolonged period. Tents and awnings protect the personnel from overheating well; their walls should not reach the ground, for better air-exchange and ventilation. Characteristic of structures in the tropics are a large roof overhang and the absence of glass in the windows. The buildings themselves usually are raised above the ground: this reduces the penetration of moisture into them. The walls usually do not reach the roof, for better ventilation.

Personal hygiene measures and a drinking schedule must be observed strictly in the tropics.

The correct choice of clothing is of great importance. Poorly fitting or tight clothing made of dense and impermeable material causes the body to overheat.

An area with poisonous animals requires special precautions.

The daily routine should be drawn up to conform as much as possible to the change in temperature. Working from 1000 to 1500 hours is undesirable. It should be kept in mind that showers, which make work on aviation materiel difficult, usually occur in the second half of the day. The best time for work is the early morning hours and the evening, when the sky usually clears.

Chapter 4

The Effect of Natural-Climatic Conditions on Aviation Fuel, Oil and the Hydraulic System Working Fluids /120

The Effect of Natural-Climatic Conditions on Fuel

The number of types of fuels, oils and working fluids has increased considerably with the development of aviation materiel, and their consumption has increased as well. Naturally, problems arose concerning their storage, removing impurities and water, preventing the development of microorganisms in them and the loss of physical and chemical properties, and so forth. These problems acquire special importance when aviation materiel is operated under complex natural-climatic conditions.

Temperature effects, dustiness of the air, atmospheric precipitation and other damaging natural-climatic factors cause change in the physicochemical, anticorrosion, lubricating and other properties of fuels. Inasmuch as interaction between the engine and fuel system components and the fuel occurs continuously during the entire time of operation, deterioration in the properties of the fuel causes many types of failures, including extremely dangerous ones. These failures may be classified as follows, according to why they occur:

from the action of impurities;

from temperature effects;

from the action of corrosion (chemical, electrochemical and biochemical);

from the action of erosion and cavitation;

from the combined action of the above. /121

Fuel may be contaminated as a result of a change in its chemical composition under the action of external conditions, as well as because of the entry of foreign particles into it (during fuel storage, fueling of the systems, through the vent system, due to destruction of fuel system parts, and so forth).

When the fuel level valve tanks become clogged they stick, as a result of which the fuel utilization sequence is upset, the tanks are used incompletely or overflow, and fuel gets into the vent system. This may cause an unacceptable change in the center-of-gravity position and fire in the aircraft.

Increased wear on the surface of the booster pump impellers occurs when working with insufficiently purified fuel, and the products of this wear also

contaminate the fuel intensively.

The high precision of adjusting the automatic fuel equipment increases its sensitivity to contamination. It is known that a reduction in engine rotor r.p.m. by 1% leads to a 3-7% loss of thrust, and an increase by 1% leads to a 14-18% reduction in the strength factor of the turbine blades. Therefore, excursions should not exceed ±0.2-0.3% for r.p.m. and ±1% for fuel consumption.

Despite careful fuel filtration before filling, the aircraft and engine fuel filters often become clogged with dust deposits, especially under operating conditions in sandy or loessial soils where the concentration of dust and sand in the air often exceeds 0.4-0.5 g/m^3 of air. Impurity particles, penetrating through the filter pores, get into the precision couplings of the fuel-metering equipment, clogging it and disrupting their operation. Seizing of the precision couplings usually involves engine stoppage (in the case of locking of the fuel pump limiting control valve, the pump plunger couplings, the fixed drop valves, the acceleration control valve, and the centrifugal control valves). Clogging of the fuel pump control valves may cause overspeeding of the engine rotor in flight above maximum permissible r.p.m.

The entry of foreign particles into the distribution valve clearance causes /122
engine surge or acceleration "hang-up" by n = 60-70% of maximum. Temporary engine stoppage in flight also is possible. This defect is difficult to determine, because it usually is not confirmed during ground inspections because the clogging is washed away by the fuel flow.

Analysis of the causes of fuel-metering equipment failures shows that at least 30% of them are the result of the action of impurities. Impurities also reduce the service life of the fuel equipment considerably. Contaminated fuel causes abrasive wear of the subassemblies. Good fuel filtering may increase the service life of subassemblies by a factor of 2-8.

Engine surge and even short-term stoppage often occur when the fuel filters are choked by foreign particles. The nature of the particles settling in the filters depends on many factors, including the place of operation of the aviation materiel. Since the particles in the fuel upon its delivery remain in the ground-based filtering devices, the fuel filters become choked primarily with particles entering the tanks during fueling and from the vent system.

Deposits of impurities in the burner channels lead to disruption of the fuel combustion process and a change in the temperature field of the gas flow, and consequently, to a sharp decrease in engine service life. When engines removed from aircraft are inspected, the following often are discovered: cracks along welded seams of the gas collector; burn-through and buckling of the walls of the combustion chamber; cracks and deformations of parts of the nozzle assembly, particularly at their attachment points; cracks of significant dimensions in the gas turbine casing; cracks, erosion, buckling and dents in the turbine and nozzle assembly blades; and there are traces of overheating on many parts. Non-uniformity of the temperature field causes dynamic loads on the blades, which sometimes may cause them to break.

The concentration and fractional composition of the impurities may change considerably during fuel transport and storage. This occurs as a result of observance or nonobservance of the rules for handling fuel, as well as because of the zone's natural-climatic conditions. Thus, the settling and filtration of fuel in depots, when the necessary precautions are observed, increases the purification quality of the fuel delivered in the Central European zone. In the desert zone, on the other hand, additional contamination of the fuel (petroleum products) by fine 1-10 μ particles of mineral origin from the dusty air occurs during storage. Settling and filtration cannot remove these particles completely from the fuel. Fuel in the tropics is contaminated by the products of corrosion of the tanks, as well as products of biological origin. /123

Intensive fuel contamination also occurs in aircraft tanks, especially in wing bays, from which it is especially difficult to remove dirt.

In addition, hydrocarbons entering the fuel oxidize during prolonged storage under the action of oxygen in the air, contact with metals, light, heat and biological factors, with the result that resins and liquid and solid precipitates are formed, which often make the fuel worthless. Tropical conditions especially further this process. Thus, for example, the following amounts of resinous products were formed per 100 ml of fuel in five months: 9 mg at a storage temperature of 15-20°C, and 53 mg at a storage temperature of 35-38°C.

The contact surface area of the fuel with the air has a substantial effect on the intensity of resin formation. It is reduced by a factor of 3-3.5 when fuel is stored in a tank filled "up to the stopper", in comparison to the

intensity of resin formation when fuel is stored in a half-filled container.

The metal of which the tank is made, as well as the water in the fuel, considerably increase the intensity of resin formation (iron - by a factor of four, aluminium - by a factor of five, zinc - by a factor of six). Therefore, attention should be paid to the selection of the material for manufacturing a fuel container.

It often is necessary to carry out fueling during a dust storm. As much as 500 g of sand may get into the aircraft tanks in this case for each 1000 kgf of fuel loaded. A large quantity of snow gets into the tanks when an aircraft is fueled during a snowstorm. Another source of dust, sand and water entering the aircraft fuel system is the vent system and the fuel tank pressurization system. Dusty air enters the tanks through the vent pipes and from the engine compressor. A large quantity of sand and dust must be removed from the tanks during routine maintenance as a result. /124

An effective means of preserving fuel system purity is the use of a closed fueling system. Improvised means must be used to protect the fillers on aircraft which are not equipped with this system.

Measures to prevent the entry of sand and dust into the fuel during its storage are simple and may be carried out easily under any conditions. It is necessary:

to see that the fillers of all tanks and the filters installed in the depots are airtight and clean;

to keep the hoses clean; their ends should be covered with clean covers;

to check the "breathing" valves of the tanks periodically and clean the dust and ice from them;

to check the condition of the inner surfaces of the tanks and take samples of the given fuel; if necessary, to clean the tanks;

to cover the tank fillers, after removing dust and ice from them, when dumping from railroad tanks and during fuel transfers.

Corrosion damage to its components by aggressive impurities in the fuel has a considerable effect on the reliability of fuel equipment operation. Previously, when the sulfur content tolerance of TS-1 fuel was considerably greater than at present, cases of chemical corrosion of parts of the pumps,

barometric regulators, fuel distributors, and throttle valves were noted. In view of this, the sulfur content tolerance was reduced to 0.25%, including mercaptan to 0.005%.

Corrosion reduces service life and causes loss of performance of fuel system components, as well as destroying them. There have been cases of destruction of the fuel pump rotor springs, the wobble plate, and other vital parts, due to an increase in friction as a result of corrosion.

Mercaptan sulfur destroys the cadmium coating on parts. Gelatinous deposits, which may clog the bores and nozzles, form in the beginning of the process and then deep corrosion cavities. This process is especially dangerous for cadmium springs working under stress. Corrosion processes are intensified considerably at increased temperatures. /125

Electrochemical corrosion occurs primarily in the presence of water, which often is contained in the fuel. Even alloy steels (ShKh-15, 12KhN3A, KhVG and others), from which the vital parts of pumps, regulators and other assemblies are made, are damaged by this type of corrosion.

Cases of the fuel filters clogging and the corrosion of fuel tanks and lines have been noted many times when aircraft are operated under tropical conditions. This phenomenon is caused by various bacteria and fungi, settling on the border of the interface of the fuel and the water residue. Products of their vital activities, consisting of organic acids, alcohols and ethers, cause intensive corrosion of the fuel tank walls, pipelines and equipment. Pockets of corrosion damage of the load-bearing elements of the aircraft structure may occur in inaccessible places in the tanks and compartments. Fungi and mold often form a film or a rather thick layer visible to the naked eye, and may cause mechanical clogging of the filters, as well as of the nozzles, burners, and vent holes.

A slimy precipitate containing impurities, bacteria, mold, and water accumulates in the lower parts of the fuel compartments. It destroys the protective coating and sealing materials under it, and through corrosive destruction of skins, panels and load-bearing elements often is observed. According to American data, large areas of the fuel compartments were damaged by corrosion in aircraft (up to 15%), primarily heavy aircraft, in certain years.

The precipitate contains a large number of aggressive ingredients secreted by fungi, mold and bacteria. Research has shown that over 100 different types of microorganisms have settled systematically in fuel systems. Fungus and bacteria spores cannot be removed by filtration; they are too small. Corrosion- /126
resistant coatings usually cannot withstand the aggressive action of the products of the vital activities of microorganisms. The exception is a coating based on epoxide resin. Sealing materials in the tanks and compartments also decompose under the action of microorganisms.

An effective means of combating microorganisms in fuel, according to foreign sources, is monomethyl ether, which is introduced into the fuel as an additive. It dissolves well in water, and a 10-15% concentration is sufficient to destroy microorganisms. Glycerine hinders the destruction of coatings and also acts as a bactericide. The Soviet liquid "I", added to prevent the formation of ice crystals, also acts extremely effectively against microorganisms.

A good means of combating microorganisms is to drain the condensate from the tanks periodically within short time intervals. This method is sufficiently effective because the growth of microorganisms is possible primarily in water, and the water in the fuel is located primarily in the bottom of the tank.

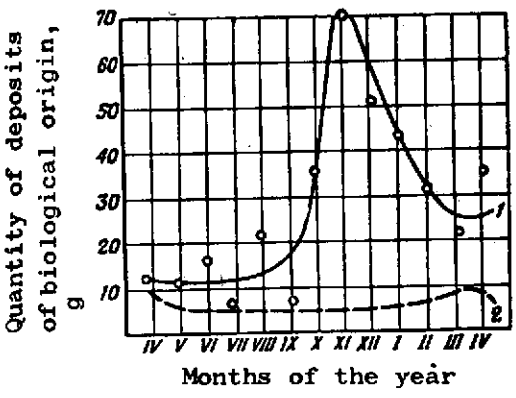

Figure 49. Growth of microorganisms in fuel: 1 - without additive; 2 - with organic boron additive.

Combating microorganisms by adding dissolved organic boron compounds to fuel is a method with good prospects for the future. Figure 49 shows the effectiveness of this means (according to the results of experiments conducted in the tropical zone). /127

The temperature of the environment has a great and varied effect on fuel characteristics.

At low temperatures, as a rule, dissolved water and high-melting hydrocarbons separate from the fuel; fuel viscosity increases, and its starting characteristics deteriorate.

Fuel evaporates quickly at high temperatures. Vapor (gas) locks form in the pipelines, which cause cavitation of the fuel pumps and reduce their

productivity. The thermal stability of the fuel is reduced and its corrosion properties are increased.

The characteristics of different fuels change differently under the effect of temperature.

Aviation fuel produced on a petroleum base is the most widely used at present in the Soviet Union as well as abroad. Fuel differ in their content of various petroleum fractions, which in turn changes their properties. All petroleum-based fuels may be divided into four types: gasolines, wide-fraction fuels, kerosenes and weighted kerosenes.

Table 13 gives the physicochemical indices of fuels.

TABLE 13

Type of fuel	Fuel specification	Density at 20°C [g/cm^3], no lower than	Temperature at start of boiling [°C], no higher than	Kinematic viscosity at -40°C [cst]	Crystallization temperature [°C], no higher than	Saturation vapor pressure [mm Hg], in the range
Gasolines	B-70	-	47			360
	JP-3	0.72	no lower than 70	-	-60	260-380
Wide fraction composition	T-2	0.755	no lower than 60	6	-60	100
	T-4	0.755	no lower than 55	6	-60	150
	JP-4	0.75	no lower than 65	-	-60	100-150
Kerosenes	T-1	0.800	150	16	-60	-
	TS-1	0.775	150	8	-60	-
	T-5	0.845	195	60	-60	-
	T-6	0.840	195	60	-60	-
	JP-1	0.78	-	10*	-60	-
	JP-6	0.78	no lower than 21	15	-54	-

* For JP-1 kerosene, viscosity is measured at -34°C.

Fuels of the last type are used primarily for ramjet engines and are not considered in this work. /128

The physicochemical properties of fuels vary greatly, and a change in them

has an extremely strong effect on aircraft performance. Thus, replacing T-1 fuel, with a density of 0.81 g/cm^3, with T-2 fuel, with a density 7% less, reduces flight endurance by 6%. An increase in fuel temperature, which decreases its specific gravity, also has a similar effect.

Fuel volatility has a great effect on aircraft altitude tolerance, as well as on flight range and endurance.

Wide-fraction fuels (T-2, T-4, JP-4) have a tendency to intensive evaporation and foaming at high altitudes. This may cause clogging of the fuel lines with vapor lock and great (as much as 30-70%) fuel losses (loss is 1-1.5% for T-1 and TS-1 fuels). Weighted kerosenes have a still lower saturation vapor pressure. At the same time, the flight range, useful load and take-off run characteristics are more advantageous when wide-fraction fuels are used (take-off run decreases by approximately 5%, range increases by almost 3%, and useful load by 8-10%). This is why JP-4 fuel is used widely in U.S. Air Force military transport aircraft. T-2 and T-4 fuels with a similar composition are used in Soviet transport aircraft.

Fuel combustion completeness is a very important index affecting the operating, economic and thrust characteristics of the engine. Deposits of carbonization and resin formation products on the nozzle and turbine blades and other elements of the gas-flow passage greatly increase hydraulic losses, cause thrust decay and an increase in specific fuel consumptions and in engine calorific intensity, as well as reducing its service life.

Fuel indices such as corrosion aggressiveness under operating conditions, stability at high and low temperatures, the presence of impurities, and anti-wear (lubricating) properties also have an active effect on the operating characteristics and service life of aircraft and engines. /129

Fuel starting properties have a decisive effect on the reliability of engine starting under conditions of high and especially low temperatures.

The rate of climb of modern aircraft is such that the temperature of the fuel in the tanks changes negligibly during climb. Figure 50 shows how the boiling point of fuel in an open tank changes sharply in relation to how much it was heated while parked. The higher the initial temperature of the fuel and its volatility, the greater the losses from evaporation. Altitude tolerance in pressurized fuel systems is characterized by the actual pressure in the tanks.

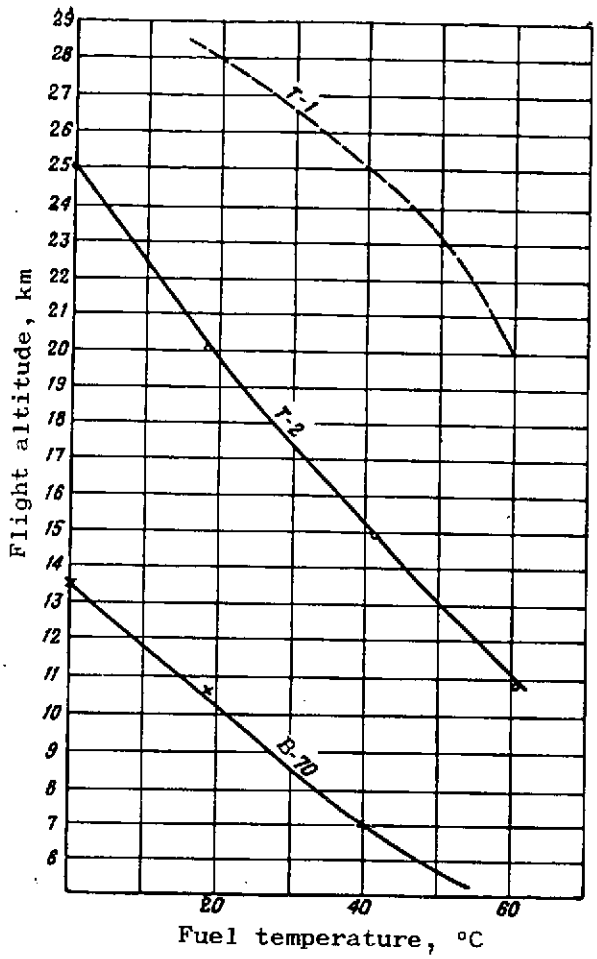

Figure 50. Relationship between the boiling point of fuel in an open tank and its heating while the aircraft is parked.

Evaporation losses may be quite high, especially if the pressurization system is unable to prevent the fuel from starting to boil. For example, there was a case of fuel coming out of the fuel-tank vent in an American aircraft. Tests were conducted at a fuel temperature of 43°C. Losses here reached 66-75% of the entire fuel volume in the tanks.

Gasoline losses from the tanks at an altitude of 18.3 km are 1-10% at an initial temperature of +5°C, and 6-19% at an initial temperature of +27°C. It is therefore advisable to use kerosenes, which have low volatility, when operating under conditions of high external temperatures.

The increased volatility of T-2 and T-4 fuel, on the contrary, is useful at low operating temperatures, because it facilitates engine starting, creates less kinematic viscosity, increases the completeness and stability of combustion, and decreases carbonization. The properties of such fuels may be improved by creating an effective pressurization system, and by introducing chemical additives or artificial cooling of the fuel in the tanks when the aircraft is parked, as is done in the B-58 aircraft, which has a ground-based cold-air unit connected to the fuel system.

The starting characteristics of kerosenes (T-1, TS-1 and others) at low temperatures may be improved in turn by introducing special additives, for example trimethylaluminium.

Temperature also has a decisive effect on the thermal stability of fuel. /130
This factor is evaluated in the U.S.S.R. by the amount of precipitate forming

in the LSA-RT instrument at 150°C in 4 hours of heating for TS-1, T-1 and T-2 fuel and in 5 hours for T-6 and T-7 fuel (GOST 9144-59). The insoluble precipitate, which settles out from the fuel when its thermal stability is insufficient, coats the inner surfaces of the fuel pump, rotor, plunger, bearing /131 and filter casings, the nozzle and burner bores, and so forth. Increased wear of parts, clogging of the filters and bores, increase in friction forces, and seizing of precision couplings are possible as a result.

The settling out of a precipitate into the oil-fuel coolers and onto the walls of the gas-flow passage causes a breakdown of heat transfer and a sharp deterioration in engine-operation conditions.

Almost all jet engine fuels become thermally unstable when heated to over 100°C. The composition of the deposits varies widely: from resinous macromolecular products (products of the oxidation of unstable hydrocarbons and organic sulfur and nitrogen compounds) to corrosion products and dust particles from the atmosphere.

Catalytically-active metals, particularly copper alloys, have a great effect on the rate of formation of the precipitate.

The precipitate settles out due to the presence in the fuel of resinous substances in an unstable state. Even slight heating of the fuel or contact between it and catalytically-active substances causes the formation of a precipitate. This brings about the constant presence of hard particles of impurities, on which the precipitation of resins with the formation of large particles begins. This process accelerates sharply as temperature increases, and the rate of resin precipitation reaches maximum at a temperature of 130-180°C (depending on the type of fuel). The rate of formation of the precipitate, as well as its fractional composition, changes here. The relative content of the larger (50-150 μ) particles increases with increase in temperature.

The process of forming a precipitate begins at comparatively low temperatures (45-70°C). The fuel darkens in the beginning because it oxidizes, and soluble resinous compounds are formed. Later these compounds form colloid particles, with the result that the fuel becomes turbid. Then the colloid particles coagulate and form a precipitate with 30-60 μ fractions. The rate of particle formation depends on the degree of heating and the thermal stability of the fuel.

Cases of fuel filters clogging in several minutes have been observed. /132

The conditions and duration of fuel storage have a great effect on the quantity of precipitate (Figure 51). An increase in the quantity of products of the oxidation of unsaturated and acidic compounds during fuel storage with a simultaneous decrease in oxidized organic sulfur and nitrogen substances considerably increases the quantity and particle dimensions of the precipitate.

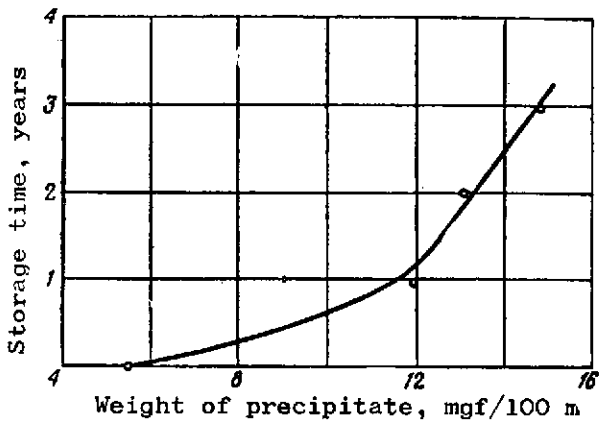

Figure 51. Effect of fuel storage time on the quantity of insoluble precipitate formed in TS-1 fuel (resin content - 0.06% by weight).

Preliminary purification of fuel improves its thermal stability (Figure 52), because the number of coagulation centers of resinous products is decreased. Thermal stability of fuel may be improved by adding anticoagulants to it and by decreasing the contact of the fuel with the air.

The low-temperature properties of the fuel in many respects determine aircraft suitability for operation at low temperatures. The present standards require viscosity at a temperature of -40°C not to exceed 6 cst for T-2 fuel, 8 cst for TS-1 and T-7 fuel, 16 cst for T-1 fuel and 60 cst for T-5 and T-6 fuel. There must be no undissolved water in the fuel, and its temperature at the beginning of crystallization must not be higher than -60°C. /133

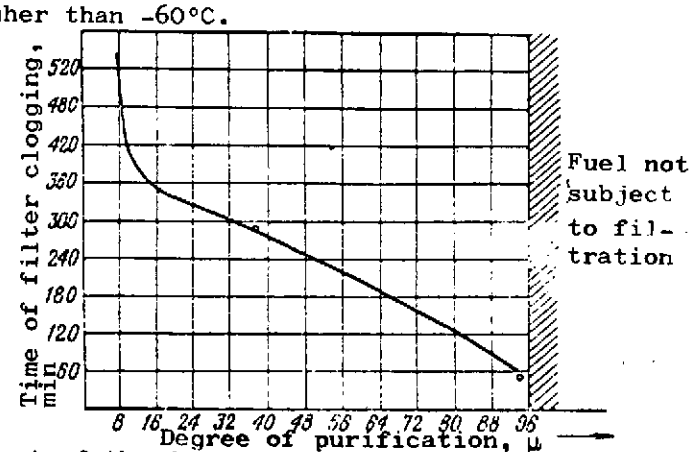

Figure 52. Effect of the degree of fuel purification on its thermal stability (time of clogging of filter element at +150°C).

These strict requirements have been introduced in order to prevent clogging of system filters and bores with ice crystals and congealed fuel, because this may lead to accidents and catastrophes. As many as 11% of the accidents in the U.S. Air Force occur for this reason, according to foreign information. Clogging of the fuel system bores usually occurs in sections placed in the airframe. Sections and devices placed in the engine do not clog, because they are heated quickly in the process of starting the engine.

Tests have shown that clogging of filters occurs at -58°C when operating with T-2 fuel, at -40°C with T-1 fuel, and at -20°C with T-5 fuel. This is linked with the fractional and chemical composition of the fuels, primarily with their water content, as well as with the change in their viscosity with change in temperature (Figure 53).

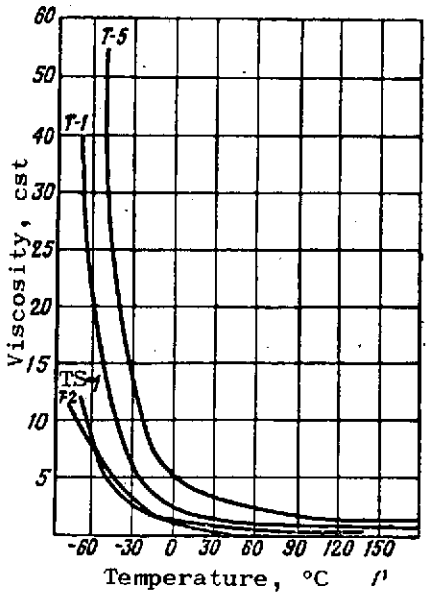

Figure 53. Relationship between viscosity of different types of fuels and temperature.

The transfer of high-viscosity fuel entails an increase in hydraulic losses, a drop in pump productivity, and a deterioration in atomization quality. A limiting viscosity value at which the power unit retains its working capacity should be established as a practical matter for each type of aircraft, depending on its lay-out, engine structure and the fuel system components being used. This viscosity value may vary widely for different types of aircraft. The increase in fuel viscosity at low temperatures occurs primarily as a result of the separation of high-melting hydrocarbon compounds with the subsequent formation of crystals. Even a 10% impurity in these compounds is sufficient to increase the temperature of the beginning of fuel crystallization considerably. Fuel turbidity upon cooling is evidence of the beginning of the crystallization process of high-melting hydrocarbons. The number of crystals increase as temperature is reduced further. The crystals coalesce, forming skeleton structures (cellular or reticular), in which uncongealed fuel fractions also are caught. The fuel thickens and congeals as a result.

/134

Dewaxing, the removal of high-melting hydrocarbons, considerably reduces fuel viscosity at low temperatures.

Water in fuel may be in emulsion form, or in a free or dissolved state (hygroscopic).

The danger of the presence of water in fuel in any form lies in its corrosivity, as well as in its ability to disrupt the supply of fuel to the pumps by settling on filter elements and walls in the form of ice. Figure 54 shows how the water concentration in the fuel affects the temperature at which the fuel supply to the engine is reduced by 20% due to clogging of the filters with ice crystals. /135

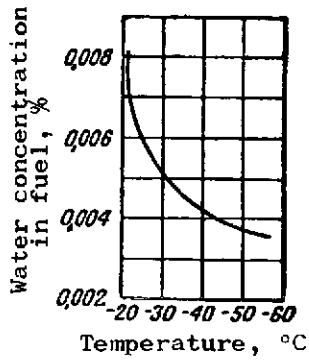

Figure 54. Change in water concentration, at which the fuel supply starts to decrease substantially, in relation to fuel temperature.

It is especially dangerous if the water is in the fuel in emulsion form. It is difficult to detect and separate from the fuel in this case. An emulsion may be very stable, because the dimensions of a water droplet are quite small (8-50 μ). The settling time of a droplet is inversely proportional to its diameter. The stability of an emulsion increases with increase in the content of resins and static electricity charges in the fuel.

An emulsion forms upon agitation of the fuel in the presence of free water or water dissolved in the fuel and separating with a change in air temperature and humidity. For example, it may form upon cooling of the fuel during a long subsonic flight at a great altitude. It has been calculated that up to 60 g of water may be separated in the form of an emulsion from every ton of fuel with a change in fuel temperature from +20 to 0°C. Droplets in a supercooled state do not change into ice even at extremely low temperatures (droplets 8 μ in diameter to -45°C, those 50 μ in diameter to -36°C). Colliding with the surface of the filter element, they instantly change into ice crystals and settle, clogging the filters.

The free water, which is not as dense as the fuel and does not mix with it, gradually settles on the bottom and the walls of the tanks. Water in such a state is easily detected and removed with the fuel residue.

The quantity of water dissolved in the fuel depends on the fuel composition /136 and temperature, as well as on air humidity. Different types of fuel have a different water solubility (Figure 55). Figure 56 shows the relationship between water solubility and kerosene temperature and air humidity.

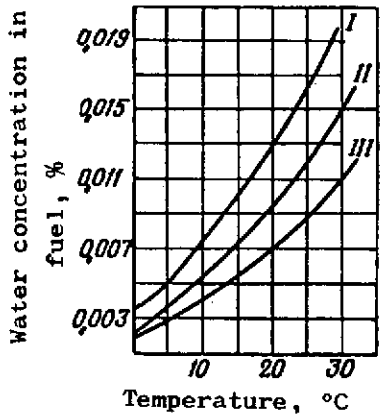

Figure 55. Water solubility in different types of fuels: I - in gasoline; II - in wide-fraction fuel; III - in kerosene.

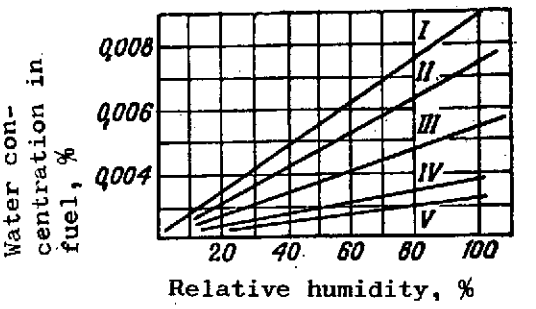

Figure 56. Relationship between water solubility and kerosene temperature and air humidity: I - t = 40°C; II - t = 30°C; III - t = 20°C; IV - t = 5°C; V - t = -10°C.

Water also separates from fuel with a decrase in atmospheric pressure, particularly with an increase in altitude (it evaporates or separates in the form of finely-dispersed drops).

So the moisture content in fuel depends on a great many conditions, which often are beyond calculation.

The filter elements are sprayed with an alcohol solution, the filter element and fuel tanks are heated, and fuel is "frozen" during storage in order to increase the reliabiltiy of the power units at low temperatures. However, the most widely used method in the U.S.S.R., as well as abroad, consists of adding additives to the fuel, which prevent the formation of ice crystals from /137 water dissolved in the fuel, even at very low temperatures. One of these additives is liquid "I" (ethyl cellosolve), which is added to the fuel in the quantity 0.1-0.3%. This quantity is sufficient to preclude ice formation to -50°C with a water content to 0.0141%. Ice crystals formed earlier in the fuel also dissolve completely within half an hour after the addition of liquid "I".

The Effect of Natural-Climatic Conditions on the Oil and Working Fluids for the Hydraulic Systems

Lubricating oil in the engines reduces friction and wear of parts and sub-assemblies, accomplishes heat abstraction, prevents scratches from appearing, removes the products of the wear of friction parts, and often serves as the working fluid in the servomechanisms. These vital functions should be performed at temperatures ranging from -50 to +150°C and higher. The high-temperature characteristics necessary for normal operation of the lubrication system more than exceed the requirements for operating conditions in the hottest climatic zones. It is precisely the qualities of aviation oil at low temperatures which determine engine starting characteristics.

The primary starting index is the oil viscosity level, characterizing its pumping quality at a given temperature. Critical temperature is that at which the oil supply is disrupted or ceases altogether. The degree of oil viscosity at which its supply is disrupted varies from 2000 to 5000 cst, depending on the lubrication system structure and the power of the starting devices. This viscosity appears in low-viscosity petroleum oils at temperatures from -30 to -35°C. Better oils should provide a viscosity of 2000-4500 cst at temperatures from -40 to -50°C, and their congelation temperature should not exceed -60°C.

Table 14 shows the physicochemical indices of aviation oils.

Oils may be petroleum or synthetic in origin. The latter provide better /138
low-temperature characteristics, but are more toxic, expensive and aggressive with respect to certain metals and industrial rubber materials. However, the continous increase in working temperatures and successes in chemistry are bringing about the increasingly widespread use of synthetic oils.

The widely used Soviet oil MK-8 had a viscosity of 7000-8000 cst at -40°C, and ensured starting without warming up only to an air temperature of -27°C. For use at lower temperatures this oil had to be poured hot into the engine and diluted with 10-15% fuel; the engine had to be kept warmed up, and therefore was started periodically and hot air blown onto it. Type MK-6 and MS-6 oils, /139
as well as synthetic oils based on diesters, ensure engine starting to temperatures of -36 to -39°C (Figure 57).

TABLE 14

Physicochemical indices	Aviation oils						
	petroleum			synthetic			
	MK-6	Trans-former (GOST 982-56)	Turboil-2 (USA)	36/1K (MRTU 38-1-157-65)	B-3V (MRTU 38-1-157-65)	VNINP-50-1-4F (GOST 13076-67)	Turboil-300 (USA)
Kinematic viscosity [cst]: at 100°C, no less than	6.0 (at +50°C)	9.6 (at +50°C)	2.43	3.5	5.0	3.2	3.5
at -40°C, no more than	3300	-	3000	3100	12300	1640	1900
Temperature [°C]: congelation, no higher than	-60	-45	-60	-60	-60	-60	-60
flash point in open cup, no lower than	140	135	132	210	250	212	215
Corrosion (in testing on metal plates by GOST 3778-56) [g/m^2]	30	none	-	none	none	none	none

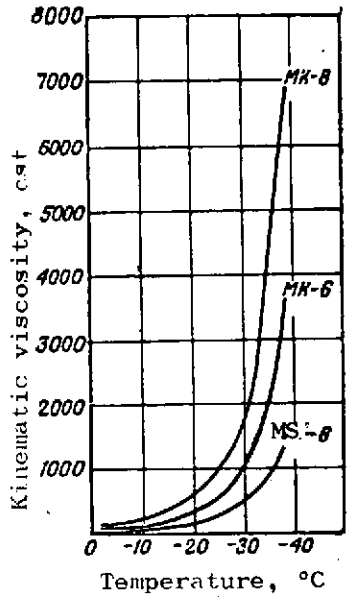

Figure 57. Change in viscosity of petroleum oils at low temperature.

When oil works in the engine for a prolonged period, its viscosity increases and its congelation temperature increases by 8-10°C. During long-term storage under low-temperature conditions an abnormal increase in viscosity is possible; therefore, viscosity must be controlled and kept within the limits provided for by the specifications. According to the specifications, the viscosity of Soviet diester oil for turbojet engines should not change by more than 6% after remaining for three hours at a temperature of -54°C. The viscosity should not be greater than 11,700 cst.

The anticorrosion properties of oils play an important role. Protective additives, corrosion inhibitors, have appeared recently and are used widely. They are admixed to oil in small quantities, and form a film on the surface of the protected metal. This film has high protective qualitites and does not permit contact between the metal surface and water, thus preventing corrosion of the metal. There are various additives. It is usually a nitrated mineral oil, neutralized and enriched with stearic acid.

Basically, natural-climatic factors have the same effect on aviation oils, especially petroleum oils, as on fuels, but to a lesser degree (the action of biological factors and impurities on aviation oils is the same as on fuels). /140

Type AMG-10 working fluid for the hydraulic systems is manufactured on a petroleum oil base. Figure 58 shows the change in its viscosity in relation to temperature. A working fluid is considered suitable for hydraulic systems if its kinematic viscosity in a temperature range of ±50°C changes by no more than a factor of 120. There is information on the loss of its lubricating properties in the tropics, where fungi and bacteria decompose the ingredients of the thickener when they get into it. All other harmful environmental factors act on this fluid the same way as on petroleum-based fuels and oils.

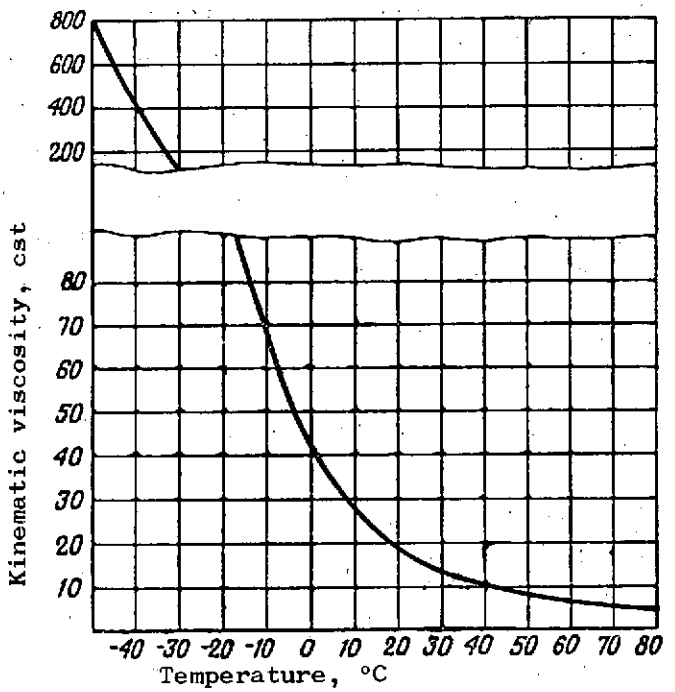

Figure 58. Relationship between AMG-10 fluid viscosity and temperature.

Chapter 5

Some Recommendations on Materials and Structure for Aircraft and Helicopters Intended for Operation in Complex Natural-Climatic Conditions /141

The preceding chapters have shown the difficulties arising in aircraft operation under complex natural conditions. Analysis of operating experience shows that operational difficulties may be decreased considerably if certain requirements are taken into consideration when designing aviation materiel. These requirements may be combined into two groups:

obligatory for all aircraft;

obligatory for aircraft intended for operation only under transpolar, desert or tropical conditions.

Any aircraft, the use of which is not precluded in complex natural conditions, should be designed with consideration for:

the use of especially durable materials and coatings;

ensuring good take-off and landing characteristics at high temperatures and low air pressures;

ensuring high passability;

the maximum sealing of compartments;

ensuring convenient access to subassemblies during operation, and the easy removability and interchangeability of subassemblies and equipment;

the completeness of ground-based equipment, providing the capability of preparing the aircraft for departure in any natural-climatic zones.

Recommendations on Materials and Coatings /142

The metallic materials used should have high fatigue strength, as well as increased corrosion resistance.

Most of the metal construction materials currently used withstand the aggresive action of the environment sufficiently well only with a good corrosion-resistant coating. When it is destroyed, corrosion destroys metal parts comparatively quickly. Fatigue strength is reduced first of all here (so-called corrosion fatigue sets in). Fatigue stresses increase around a section damaged by corrosion, and the negative electric potential increases at the same time. The sections become anodes, and the process of their destruction is accelerated

sharply by electrochemical reactions. Moisture condensing from the air contains dissolved salts and oxides of sulfur, nitrogen, carbon and other substances. It therefore becomes an active electrolyte. Corrosion processes take place most intensively in coastal and tropical regions and in regions with dusty air.

A special feature of the corrosive destruction of aircraft units is that it is primarily closed sections that are damaged (riveted seams, blind compartments, etc.). This is quite dangerous because the more oxidized sections, where oxygen plays the role of a depolarizer, become cathodes and the surfaces, surrounded by air with a reduced oxygen content, become anodes, and consequently are destroyed more quickly. Maximum protection must be ensured and the most attention during inspection given to the metal surfaces of closed compartments.

The correct selection of contact and connection materials, taking into account their electrochemical parameters, plays an important role. Otherwise the material of the parts which are the anode in the given connection is destroyed quickly.

Cathod coatings are characterized by a positive potential with respect to the material of the part (for steel this is tin, copper, chromium or nickel). Breaking of the cathode coating causes rapid destruction of the basic material, which is the anode then. Therefore, these coatings may be used as corrosion-resistant coatings under complex operating conditions only when there is slight probability of their damage and access for their inspection is possible. It is very important that the coatings be of sufficient thickness and high density. /143

Anode coatings (zinc, cadmium) destroy themselves while protecting the basic material. Passivation (for example, by a potassium bichromate solution with sulfuric acid added) is used to increase the durability of the anode coating. Zinc coating is unsuitable in complex operating conditions. Cadmium plating is somewhat more practical, especially for coastal regions.

Stainless steels and refractory alloys also are vulnerable to corrosion, and to its most dangerous form, intergranular corrosion, when the process develops along the grain boundaries. Carbides, entering the steel structure in the form of grains, deplete the chromium content in the material sections adjacent to the grain boundaries, which become strong anodes and cause intensive destruction of the austenite anode area. The process takes place quickly and develops to a great depth. The injection of niobium and titanium to steel,

as well as heating for two hours and more at a temperature of the order of +900°C increases corrosion resistance somewhat.

Aluminum alloys have sufficient corrosion resistance, but they may corrode intensively in the presence of soil salinity and salt-water vapors and spray.

Some alloying elements and admixtures (copper, nickel, iron), which are constituents of aluminum alloys, further the formation of cathode sections and, consequently, accelerate electrochemical corrosion.

Type AMts, AV, AL-8, and AMg alloys have comparatively good corrosion resistance.

Type duralumin (D16, VD-17), V-95, V-96, AK-6, and AK-8 high-strength alloys require special protective measures, because they have comparatively low corrosion resistance.

Plating, anodizing with subsequent passivation, chemical oxidizing, paint-and-varnish coatings, and protective lubricants are used to protect parts made of aluminum alloys. Anodizing and paint-and-varnish coatings provide the most /144 effective protection.

Magnesium alloys have low corrosion resistance; their use in complex natural-climatic conditions complicates operation considerably and, consequently, is inadvisable.

Fabrics of metal fibers have appeared recently, which have sufficient flexibility and increased resistance to the action of high and low temperatures, solar radiation and biological factors, in contrast to engineering cloth and polymer fabrics.

The use of all-metal and fluoroplastic pipes and hoses prevents the operating inconveniences associated with the drawbacks of rubberized-fabric hoses.

Corrosion damage to power structural elements made of high-strength alloys presents an exceptional danger. There have been cases of the sudden destruction of the stabilizer beams, the undercarriage legs, and the wing joints. Corrosion begins along the grain boundaries touching the surface, which is in a stretched state, especially where the layers which occur in stamping are cut in the mechanical treatment process. This type of corrosion must be prevented by, in

addition to an effective coating, carefully designing the stamps to obtain the most favorable spreading of the metal, cooling the forged piece in hot water to reduce the residual stresses, reducing to a minimum the volume of mechanical treatment after stamping to keep the surfaces in an untreated state, using surface hardening methods (shot blasting, rolling, and so forth), mounting fastenings (bolts, rivets) in a liquid primer, treating the inner surfaces of openings under fastenings, and decreasing the area of contact between heterogeneous materials. The ends of bolts and rivets should be covered with a thick primer to prevent moisture from getting into the gap.

Lamination of aluminum skins along the edges of the openings under bolts and rivets also presents great danger. This occurs as a result of intergranular corrosion, which damages the grain boundaries touching the surface of the openings and spreads along the grain boundaries parallel to the skin surface (Figure 59). Swelling of the skin due to the increase in the volume of corrosion products is a sign of such corrosion. The U.S. Air Force, as a result of intergranular corrosion of the skin which damaged KC-135, C-130, F-101 and F-102 aircraft, had to replace the skin on almost the entire park of these aircraft. In view of the difficulty of detecting this type of corrosion in the early stages of its development, the skin surface must be inspected carefully for timely detection of swelling around bolt and rivet heads. /145

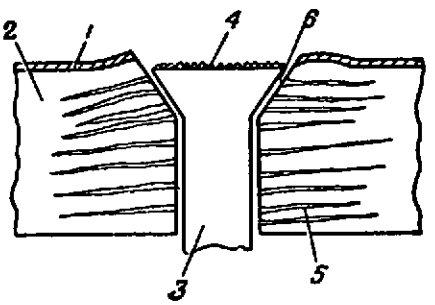

Figure 59. Skin lamination due to intergranular corrosion: 1 - plating layer; 2 - skin panel; 3 - cadmium-plated steel bolt (rivet); 4 - corrosion; 5 - intergranular corrosion; 6 - gap occurring because of the difference in diameters and deviations in dimensions.

The best means of preventing intergranular corrosion at present is the mounting of bolts and rivets in a liquid primer, which prevents moisture from getting into the gap between the rivet and the opening. The protruding surfaces of fastenings and primary and snap heads must be painted.

The electrochemical processes occurring upon contact of heterogeneous materials play a major role in the lamination of aluminum skins, because cases of lamination of aluminum skins under aluminum rivets have not been established.

One of the most dangerous types of corrosion is point damage, which appears on thin (1 mm and less) plated duralumin skin panels. Point corrosion in tropical conditions may damage the greater portion of the skin within 6-8 months of aircraft operation. Cases of water entering the inner chambers of the control surfaces through corrosion cavities have been noted, which led to aircraft unbalance and a loss of anti-flutter characteristics. Painting the skin is a means of combating point corrosion. /146

Point corrosion damages thick-walled parts and units, as well as the skin. Incorrect use of solvents, polishing pastes, and other aggressive substances may cause intensive point corrosion subsequently.

Polishing and plating the surfaces of unpainted structures was considered a sufficiently effective anti-corrosion means until recently in the U.S.A. Protective painting of surfaces now is obligatory in the U.S.A., as well as in England. It has been established that restoration of coatings and elimination of the consequences of corrosion is four times as expensive as painting the surfaces at the factory. Adding inhibitors to paint-and-varnish materials is quite effective against corrosion (even in a proportion of $20:10^6$). Calcium chromate and strontium chromate are used widely as inhibitors.

The thickness of the paint-and-varnish coating is very important but an excessively thick layer leads to an unjustified increase in weight, as well as having poorer adhesion (adherence) to the basic material.

Paint-and-varnish coatings are damaged intensively by fuel, oil and working fluid, and must be protected from their action. It is known that in the beginning of the 60's the U.S.A. took hundreds of aircraft out of service due to strong corrosion of the skin and especially of structural elements located in the fuel compartments. Replacement of the units and parts damaged by corrosion alone cost tens of millions of dollars. The annual expenditures, according to the estimate of the Rand Corporation, for the repair and replacement of aircraft put out of service by the action of corrosion are now 1 billion dollars in the Air Force and 600 million dollars for Navy aircraft.

It is advisable to use protective coatings with the following properties on aircraft operated under complex climatic conditions:

a water-repellent nature; that is, the inability to retain water, ice and dirt on its surface; /147

high elasticity;

high light- and ozone-resistance;

high resistance to erosion by sand and snow;

high resistance to the action of microorganisms and other biological factors;

high resistance to the action of salts and acids:

high heat and moisture-resistance;

good maintainability; that is, to make possible qualitative repair under non-hangar conditions.

A common drawback of many of the protective coatings used is the difficulty or impossibility of restoring them in the process of operating aviation materiel, especially under airfield conditions. Moreover, the intensity of corrosion destruction processes requires the restoration of a coating immediately after it is damaged. Paint-and-varnish coatings satisfy this important requirement to a greater extent.

For aircraft intended for operation under complex climatic conditions, particularly under tropical conditions, the question of the quality of the coatings is to a great extent a question of ensuring service life. The destructive factors noted in the preceding chapters cause the rapid failure of a subassembly whose protective coating for some reason fails to create reliable protection. Access to the inner compartments of an aircraft or helicopter during operation and repair becomes difficult. Therefore, the coating should be applied to each part, especially one mounted in blind compartments, before joining it to other parts. The thickness, number of layers, and the selection of the paint-and-varnish coating depends on the material of the part, its working conditions, and the possibility of checking on it during operation, as well as on the possibility of renewing the paint-and-varnish coating during repair.

The scheme shown in Table 15 may be used when applying coatings to parts made of aluminum alloys.

The "+" sign indicates that the sections are finished (painted) according to the scheme shown in Table 15.

Varnish-and-oil, glycerol-phthalate, pentaphthalate or perchlorvinyl paint-and-varnish materials are widely used at present. /148

TABLE 15

Type of protective treatment (coating)	Access available				No access			
	Sections subject to moderate corrosion	Sections subject to action of water, fuel or oil	Sections subject to action of aggressive fluids	Sections subject to mechanical actions and vibrations	Sections subject to moderate corrosion	Sections subject to action of water, fuel and oil	Sections subject to action of aggressive fluids	Sections subject to mechanical actions and vibrations
Chemical treatment of metals	+	+	+	+	+	+	+	+
Anode coating with potassium bichromate filling	+	+	+	+	+	+	+	+
Coating with a hot-drying primer	+	+	+	+	+	+	+	+
Epoxy-based paint-and-varnish coating	+	+	+	+	+	+	+	+
Epoxy-nylon (or similar) varnish	-	-	+	+	-	+	+	+

The ALG-1 varnish-and-oil primer has shown good protective properties under the most varied operating conditions, but has little resistance to biological factors (fungi, mold). It is often used together with 138A glycerol-phthalate primer.

Chlorinated rubber coatings or chlorinated alkyd resin coatings, as well as paints pigmented with titanium dioxide and made on these bases, have shown good resistance to the action of biological factors. They were almost invulnerable to destruction by fungi during tests under conditions of high humidity (83-87%) and temperatures of 14-31°C.

It is advisable to use perchlorvinyl enamel (two-three coats), which has a high durability, for painting the aircraft's outer surface. However, a primer

must be applied to the surface first, because it has weak adhesion. The BAC company (England) applies a paint-and-varnish coating based on epoxide resin to the surface of all parts of the airframe structure. This coating has high adhesive properties, and is elastic and heat-resistant. The durability of the coating is guaranteed for 30,000 flight hours (for transport aircraft). /149

The application of two or three coats of 9-32 varnish, which has fairly good resistance to the action of moisture and sunlight, gives good results aginst corrosion. 9-32A1 enamel is manufactured on its base (with aluminum powder added).

Siloxane enamels retain their protective properties in a wide range of temperatures.

At the same time, many of the paint-and-varnish coatings used are not yet sufficiently perfected, especially with regard to their working properties. The technology of applying them is labor-consuming, and special precautions are required for protection from the action of cold, moisture and dust, which causes considerable difficulties in operating conditions.

Ceramic enamel coatings, which protect metal well from oxidation, general intergranular corrosion, erosion and wear, have been used widely recently, especially in engine manufacturing. Their use permits economizing on expensive high-alloy steels.

The constituents of these coatings are oxides of aluminum, zinc, titanium, manganese, chromium, silicon, beryllium, magnesium, zirconium, nickel, cobalt, and others.

The most complex problem in making and using them is ensuring equality of the linear expansion coefficients of the coating and the protected part.

Ceramic enamel coatings are applied by flame spraying or dipping. The thickness of the coating is 0.12-2.5 mm. The use of this type of coating for aircraft structural parts, especially the undercarriage, is very promising.

Substances of organic origin usually are used as non-metallic structural materials. They include the binder (synthetic resins), fillers (fabric, fibrous materials, mineral powders), plasticizers, dyes and other constituents. These materials usually are called plastics, and break down into thermoplastic and /153

TABLE 16

Name of polymer (copolymer)	Range of working temperatures [°C]	Main purpose (what is made from them)	Effect of solar radiation, oxygen and ozone	Moisture resistance	Inflammability	Possibility for use in complex operating conditions
Polyethylene: low density	+60 to -60	Films for preserving equipment, fuel tanks, insulating materials	Ages intensively	High	Weak	Should not be used
high density	+80 to -60		"	"	"	Use limited
Polypropylene	+120 to -30	Films, pipe, sheets	"	"	"	Should not be used
Ethylene and propylene copolymer (EP)	+120 to -70	Films, pipe, molding material	Ages intensively without stabilizer	"	"	Use permitted
Polyisobutylene	+40 to -50	Sheets, films, containers, glue, synthetic rubber	Does not age, for practical purposes, very ozone-resistant	"	"	Use limited
Polyvinylchloride (PKhV)	+60 to -10	Containers, sheets, films, fibers, pipe, insulation, foam plastics	Ages quickly without stabilizer	Good	"	Should not be used
Polyvinylchloride copolymer	+120 to -40	Films, fibers	Properties change negligibly	"	"	Use limited
Perchlorvinyl	+60 to -30	Glue, varnishes, fibers	"	"	"	Use inadvisable

TABLE 16 CONTINUED

Name of polymer (copolymer)	Range of working temperatures [°C]	Main purpose (what is made from them)	Effect of solar radiation, oxygen and ozone	Moisture resistance	Inflammability	Possibility for use in complex operating conditions
Polyvinyl-fluoride	+120 to -60	Plastics, sealants	Properties change negligibly	Good	Does not burn	Use advisable
Fluoroplastic-3	+150 to -180	Plastics, films, fibers, sealants, synthetic rubber, porous plastics	"	"	"	"
Fluoroplastic-4	+200 to -200					
Polystyrene	+70	Foam plastic, sheets, pipe, emulsions, containers	Quite stable	"	Weak	"
Polymethyl-methacrylate	+80 to -50	Sheets, varnishes, glue, molding powders, containers	Oxygen-resistant, but sensitive to radiation	"	Good	Use permitted
Polyacrylonitrile	+200	Fibers, rubber, fabric, heat insulation	Stable	"	"	"
Polyamides	+195	Biologically stable fabrics, gasoline- and kerosene-resistant sealants	Unstable	"	Weak	Use permitted when service life limited
Terephthalic polyethylene glycol (lavsan)	+150 to -60	Biologically stable fabrics and canvas, films	Stable	"	"	Use advisable

TABLE 16 CONTINUED

Name of polymer (copolymer)	Range of working temperatures [°C]	Main purpose (what is made from them)	Effect of solar radiation, oxygen and ozone	Moisture resistance	Inflammability	Possibility for use in complex operating conditions
Polyacrylates	+200 to -50	Plastics, fibers, films, foam plastics	Very stable	Good	Weak	Use advisable
Celluloid (nitrocellulose)	+60 to -30	Nitrolacquers, nitro-cellulose glue, sheets	Not light-resistant	"	High	Use not permitted
Phenol-formaldehyde (resol) resin	+100 to -20	Laminated plastics, glue, varnishes, foam plastics, sealants	Stable	"	Does not burn	Use limited
Resorcinol-formaldehyde resin	+100 to -60	Same	"	"	"	"
Epoxide resins	+130 to -60	Glue, varnishes, mastic, fiberglass-reinforced plastics, compounds	Need protection from direct solar rays	"	"	Use advisable
Polyester urethanes	+300 to -190	Plastics, films, fibers, foam plastics, synthetic rubbers, glue, cloth-skeleton and radio-transparent parts	High ozone-resistance	"	Burn	"

TABLE 16 CONTINUED

Name of polymer (copolymer)	Range of working temperatures [°C]	Main purpose (what is made from them)	Effect of solar radiation, oxygen and ozone	Moisture resistance	Inflammability	Possibility for use in complex operating conditions
Furan resins	+200 to -70	Fiber-glass-reinforced plastics, wood-fibrous plastics, varnishes	Good light-resistance	Good	Do not burn	Use advisable
Silicones, organic silicones	+350 to -90	Resins, glue, varnishes, fiber-glass-reinforced plastics, rubber, foam plastics, lubricants, fluids, water-repellent coatings	High light-resistance	"	"	"

thermosetting plastics. The first soften with each repeated heating, while the second retain the shape once given them after polymerization (become thermally stable).

Plastics are subdivided into structural-power plastics (for loaded parts), non-power plastics (for panels, facings, and so forth), light-transparent plastics (for cabin glazing), radio-transparent, electric-insulating, sealing, heat-insulating, acid-proof and antifriction plastics.

Table 16 shows some non-metallic structural materials (polymers), their main purpose, moisture resistance, inflammability, and resistance under the action of solar radiation, oxygen and ozone, as well as giving recommendations on the possibilities for using them under complex operating conditions.

Recommendations on Landing Gear

Unfavorable temperature and barometric conditions observed in different zones of the earth, and in mountainous regions for the greater part of the year, make increased requirements of the landing gear. The combination of these conditions and the shortage of well-equipped airfields, and often their complete absence, makes the satisfaction of these requirements still more necessary.

Therefore, the following must be provided for when designing an aircraft:

landing gear with a shock absorber with increased working capacity (for example, two-chamber and levered wheel suspension); with wheels with powerful braking devices, low-pressure or better, variable-pressure, tires and increased area of contact with the surface (the use of wheel-ski, ski or track-type landing gear is possible); with a passability ensuring operation from ground with a strength of no more than 3 kgf/cm^2;

additional braking devices (brake parachute, hook, and the like);

improved view in take-off and landing; /154

equipment that is highly vibration-proof and has good shock absorption.

Recommendations on Engine Structure

Engine structure should take into consideration its possible use under complex natural-climatic conditions, and provide for the following:

high surface hardness of the compressor blades to reduce erosion;

compressor anti-icing devices (preferably of increased power);

the possibility of cleaning (washing) the engine gas-air-flow passage during operation to remove dust and deposits;

protection of the fuel-metering equipment from the action of dust;

a configuration for the compressor casing which would reduce the accumulation of dust to a minimum;

increased surge margin, which makes it unnecessary to reregulate the engine with change in outside air temperature;

an arrangement of the air scooping points in the engine for cabin pressurization, the boundary-layer blowing system, and the fuel system which would reduce the entry of dust into them to a minimum;

protection of the compressor from the entry of small, hard objects (pebbles, ice particles, and the like) from the runway;

convenient access for checking the condition of the blades and other vital engine components during operation;

power reserve of the lubrication and cooling systems;

increased acceleration capacity and the possibility of short-term thrust augmentation.

Recommendations on Sealing the Aircraft Structure

Structure air-tightness may, without exaggeration, be called the main reserve for facilitating the operation of aviation materiel under complex natural-climatic conditions. An aircraft with well-sealed compartments is protected /155 from the action of unfavorable natural factors, is always ready for immediate departure, and minimum labor expenses are required for servicing it. In order to ensure the air-tightness of aircraft compartments, it is advisable to:

use only hatches with a sealed structure (hatches should have hoses or other sealing devices);

provide for closed cargo suspension;

install reliable seals on landing gear and armament hatches, and the like;

use a "seating" system for the landing gear hatches, which anticipates their closing after the landing gear is down;

reduce to a minimum the number of openings (intakes) on the aircraft surface for venting, cooling, pressurization, and other purposes, to ensure their easy closing when the aircraft is parked; group openings when possible and locate them in one place;

pressurize tanks from bottles, and when necessary from the engine, with reliable filtration of the air supplied for pressurization.

Recommendations on Aircraft Lay-Out and Some Structural Elements

Aircraft lay-out should ensure the following:

improved view during take-off and landing under conditions of poor visibility, low contrast and small runway dimensions (this may be ahcieved by good cabin glazing and appropriate nose curve contours);

the installation of equipment facilitating piloting during flight over unmarked terrain and under conditions of poor visibility;

good maintainability;

an arrangement of the engine air intakes, camera hatches, cabin glazing, vent and drain openings, ventilation branch pipes, controls, and the rifles and machine-guns, so they do not enter the "splashing fan"; this prevents damage to them by streams of water, ice, mud and broken stones during take-off and landing;

closed filling of the aircraft tanks with fuel and oil, and of the hydraulic /156
system with working fluid;

an arrangement of the fuel system fillers and vent branch pipes whenever possible in areas shielded from electrical discharges.

In addition, hinged joints must be provided with devices ensuring their lubrication and sealing and protecting them from impurities, and reliable protection of the actuation cylinders from destruction by sand particles and rocks must be provided.

Recommendations on Equipment and Its Arrangement in the Aircraft

For most stable, reliable operation and convenience in equipment operation, it is necessary to:

reduce to a minimum the use of protruding antennas to prevent their destruction by the covers;

locate static discharges in places ensuring their effective use (Figure 60 shows an operating diagram of such a discharger); corona dischargers supplied from a high voltage power source are more effective; they ionize the adjacent air layer and facilitate the flow of charges from the aircraft (Figure 61); Figure 62 shows the effectiveness of dischargers;

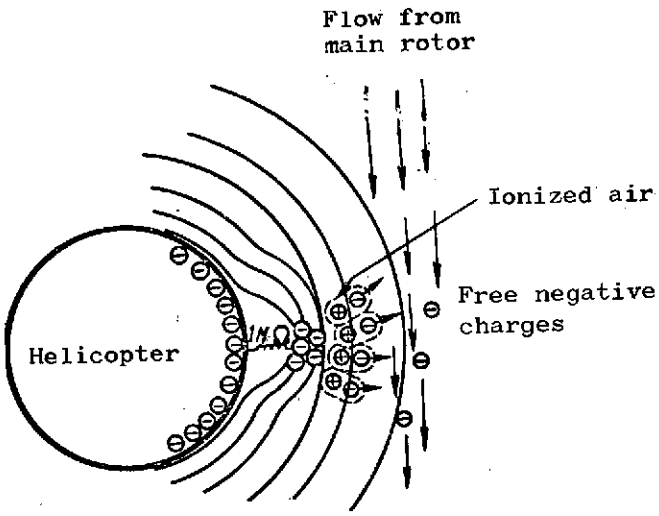

Figure 60. Operating diagram of a passive static discharger.

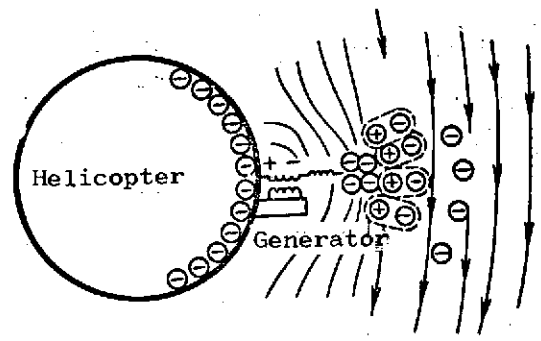

Figure 61. Operating diagram of a corona (active) discharger.

ensure good electrical contacts between aircraft structural elements, especially the fuel tank filler caps and the bonding strips of the control surfaces, preventing sparking when a current of great strength occurs upon a lightning discharge, to prevent fire, radio interference upon spark discharges, and damage to the bearings at the suspension points of the control surfaces;

fit non-metallic surfaces (antenna fairings, fiber-glass honeycomb panels, etc.) with metal conducting bridges, which, arranged on the surface, should provide for the passage of radio waves and make it possible for the electrostatic charges and lightening discharges to flow on the skin;

make all equipment blocks of instruments and completing articles sealed;

ensure easy access to equipment for inspections, as well as its easy removability; /157

ensure a length margin for conductors when installing wiring to compensate for it during temperature changes;

ensure that the operating temperature conditions of blocks and devices are not dependent on external temperature conditions; /158

conduct preliminary tests of the service life of all systems and their components with the combined action (in the most unfavorable combinations) of the natural factors;

do not lead wiring onto the aircraft's external surface, because then the actuating devices (locks, explosive charges, electric valves, and the like) may /159

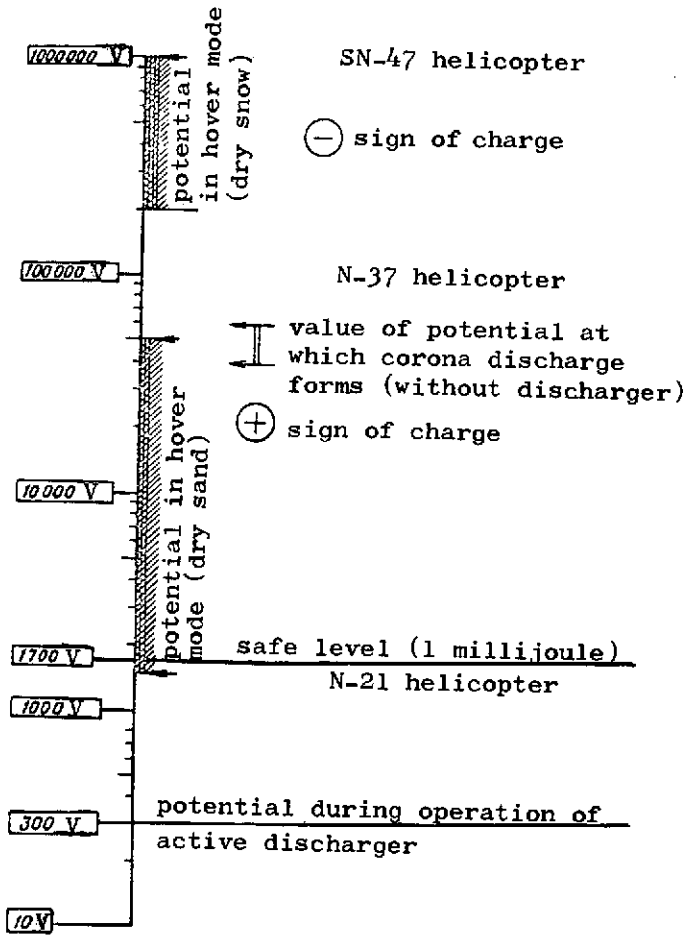

Figure 62. Electrostatic potentials formed on helicopters, and the comparative effectiveness of different types of dischargers.

start operating spontaneously upon an electrostatic or lightning discharge;

do not use rubber shock absorbers (highly effective are shock absorbers with metal springs and damping units, for example, type AFD, Vibrachoc, Barry and others; see Figure 27);

use automated control systems;

make it possible to connect the air conditioner for ventilating the cabin and instrument compartments with air of the required temperature while parked.

Recommendations on Ground-Based Equipment and Special Transport

Ground-based equipment and special transport should have:

increased passability and support area;

minimum weight and dimensions which make it possible to ship this materiel on transport aircraft;

corrosion resistance appropriate for the requirements presented by the materiel being serviced;

completeness, ensuring the operation of aviation materiel under various natural-climatic conditions.

In addition, ground-based equipment and special transport should be all-purpose and have increased air-tightness of all checking devices and rigs. This makes it possible to use them in any areas of the earth.

Recommendations on a Transpolar Version of an Aircraft

An aircraft intended for operation exclusively in transpolar regions should have a cabin and compartment heating system of increased power, a turbine cooling unit of reduced cooling capacity, as well as heating of instrument glasses. A luminous material, which does not lose its capacity to glow under conditions of the polar night, should be used for the instrument readings of such an aircraft, /160 and the rubbers and plastics used in it may have a temperature range shifted to the side of negative temperatures, but ensuring their plasticity at temperatures as low as -60 to -65°C (fluorine-based rubbers). It should be made possible to dump fuel for the pilot's use during a forced landing; moreover, reliable emergency communication should be provided for. Parachutes should be brightly colored.

Ground-based equipment and special transport should include:

a cabriolet-type tent adjoining the aircraft for working in aircraft compartments under blizzard conditions;

columns for centralized fueling of aircraft tanks;

power supply columns for supplying the electric heaters and utility lamps;

floodlights for illuminating the parking areas;

portable hangars for repair operations;

sets of airtight covers with increased strength;

sets of protective covers for all openings, intakes and wells.

All special transport should have an undercarriage with increased passability, and even better, on caterpillar drive.

Recommendations on a Tropical Version of an Aircraft

An aircraft intended for operation under tropical conditions should have:

increased engine thrust at high outside air temperatures;

increased power of the cabin and compartment cooling systems;

reduced power of the heating systems.

Materials with antiseptics and fungicides added (rubbers, plastics, fabrics, and so forth), as well as heat- and biologically-resistant metal gauze fabrics, should be used in such an aircraft.

Rubbers and plastics used in such an aircraft should have a temperature range /161 shifted to the side of positive temperatures (silicone-based rubbers). Lubricants should ensure normal operation of the joints at high temperature and humidity. It is advisable to use solid lubricants (for example, a multi-ingredient compound of ceramic lubricant, molybdenum disulfide, graphite, and others). Joints in which solid lubricants are used can operate at a contact pressure of up to 700 kgf/cm^2 and a temperature of over 300°C.

Ground-based equipment should include sets of awnings for shading working areas and aircraft structures; air conditioners for cooling the cabins, equipment bays and fuel compartments; airtight tents for conducting laboratory tests and repair operations; and a set of protective covers treated with antiseptics and toxic substances. The covers should be airtight and have increased strength.

Special transport should have increased passability.

Some Recommendations on Helicopters

Helicopters designed with consideration for the possibility of their use under complex natural-climatic conditions should have power ensuring the hover mode at high temperatures and low atmospheric pressure. Only under this condition will they be capable of performing their duties in mountainous regions with a hot climate. An analysis of the data given in Figure 5 shows that the critical values for determining the technical possibilities of a helicopter in these regions are the mean diurnal maximum temperature for the warmest month and the atmospheric pressure (height above sea level). The first value is a sufficiently convenient and comprehensive temperature characteristic for any region. It has been established as a result of many years of observation that the possible diurnal deviation from this value (toward its increase) does not exceed 2.7°C with about 90% probability.

The natural-climatic conditions most demanding for helicopters are those characteristic of the Near East and Central Asia, as well as certain countries in Latin America. /162 The combination of hot climate and mountainous relief of the terrain, low atmospheric pressure and the poorly developed network of communications and airfields makes the operations of ground-based transfer equipment and aircraft difficult in these regions. Therefore, helicopters acquire special value here, providing, however, that they retain the capacity for vertical take-off and landing with the design payload and full fuel capacity.

An analysis of helicopter hovering characteristics under various climatic and natural conditions shows that when drawing up the technical requirements for helicopters one should be guided by the mean diurnal temperature maxima and the barometric pressure values characteristic for the southwestern part of the Asian continent. Even the mountainous conditions of the Himalayas and the Andes are less demanding for vertical take-off and landing characteristics, due to comparatively low temperatures.

The technical requirements for characteristics in the hove mode differ widely. The old standards for helicopter design in the United States required a helicopter to be able to take off and land vertically (without regard for the effect of the earth's proximity) at a height of 1830 m above sea level and a temperature of +3.3°C (curve IV, Figure 5). In England, because of the experience of the war in Malaysia, it was considered necessary to have the same characteristics at a height of 1530 m and a temperature of +30°C (at a height of 1830 and at +25.6°C) (curve III).

Modern French helicopters are designed based on the need to ensure the hover mode at a height of 1830 m and a temperature of +30°C (curve II, Figure 5). U.S. Air Force helicopters are required to take off and land vertically at heights of 1830 and 2100 m (for heavy and medium helicopters, respectively) and a temperature of +3.3°C.

The insufficient operating effectiveness in South Vietnam of helicopters built according to the old technical requirements forced the U.S. Air Force to review the requirements. Modern U.S. helicopters are built in accordance with new requirements, which provide for the capability of vertical take-off and landing at a height of 1830 m and an outside air temperature of +35°C (curve I, Figure 5).

Table 17 gives the time (in %) in which air temperature and atmospheric pressure exceed the limits on which the characteristics of U.S., British, and French helicopters are calculated during operation in the most demanding natural-climatic conditions. /163

TABLE 17

Technical requirements	Time (in %) in which air temperature and atmospheric pressure exceed the limits on which the characteristics of U.S., British, and French helicopters are calculated during their operation in				
	Southeast Asia	Southwest Asia	Iran-Saudi Arabia	Afganistan and Pakistan	Eastern Mediterranean
U.S.A. (old), H = 1830 m, t = 3.3°C	100	100	100	100	100
England, H = 1830 m, t = 25.6°C	10	41	55	47	11
France, H = 1830 m, t = 30°C	3	16	30	19	2.5
U.S.A. (new), H = 1830 m, t = 35°C	0	3	9	2-3	0

Table 17 shows that U.S. Air Force helicopters designed according to the old tactical-technical requirements (TTR) as a practical matter could not ensure the design characteristics in the regions indicated. Helicopters designed according to the new requirements can be operated in these regions with no limitations.

Analyzing the characteristics of helicopters designed according to different TTR (curves I-IV in Figure 5), one is convinced of the superiority of the helicopters built according to the new TTR. The U.S. helicopter (curve I, Figure 5) can hover at a height of 3500 m and a temperature of 0°C.

It can be established by computing the area of geographical maps that helicopters designed to ensure hovering at a height of 1830 m and a temperature of + 35°C can, carrying the design payload, accomplish the mission successfully

above 87% of the territory of Southeast Asia.

Helicopters of the future should ensure hovering at a height of 2000 m and a temperature of 40°C (curve V, Figure 5). Such helicopters will have greater operating effectiveness, as well as a certain power (thrust) reserve necessary to overcome turbulence and descending air currents, to compensate for the increase in weight of the helicopter structure with time due to structural changes, repairs, and the installation of new equipment, and to compensate for the loss of flight characteristics due to engine wear and deterioration in the surface qualities of the blades and fuselage. /164

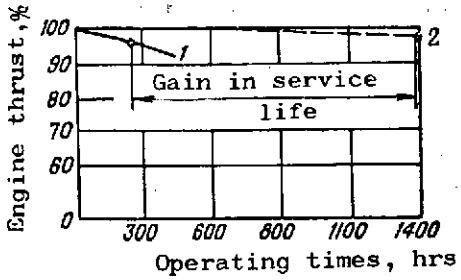

Figure 63. Effectiveness of the use of a dust separator: 1 - without dust filter; 2 - with dust filter.

All helicopter engines should be fitted with air purification devices of the self-cleaning dust separator type. Such a separator requires minimum labor expenses for servicing and removes up to 90% of the dust entering the engine inlet. The power losses in operating the separator are negligible (2-3%) and the separator may be disconnected when there is no dustiness. The pressure losses at the engine inlet when this device is used are 100-110 mm H_2O, depending on the structure. As seen in Figure 63, the use of a separator increases engine service life by a factor of more than five, while helicopter flight performance does not deteriorate for practical purposes and fuel consumption increases by approximately 1%.

Units for protection from lightning and electrostatic discharges should be provided for in the blade structure. The leading edge and the flow edge, therefore, should be joined by metal strips every 300 mm, which hinders the penetration of the discharge into the blade structure and prevents its destruction. /165 Dischargers should be mounted on the ends of the blades so the electrostatic charges flow off. The discharger structure shown in Figure 64 has considerable advantages. This discharger is extended from the blade only upon the operation of the main rotor under the action of centrifugal forces.

A potential of over 1,000,000 V may be created in the hover mode with the action of dry snow or sand on the helicopter. Loading-unloading operations

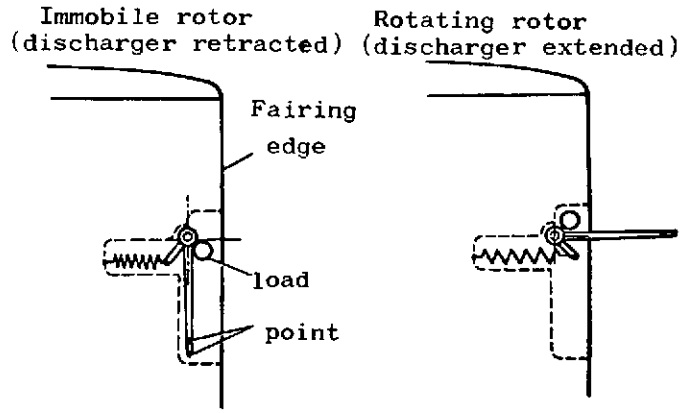

Figure 64. Retractable discharger for helicopter blades.

become dangerous with such a potential, and, moreover, fuel ignition is possible. Passive dischargers cannot reduce the potential to a safe magnitude, 1700 V (a safe charge is 1 millijoule). Grounding the helicopter works reliably only above a water surface. The safety of loading-unloading operations may be ensured only by using an active discharger (Figure 61). Such a discharger has been mounted in the SN-47A helicopter (U.S.A.) and reduces the potential to 300 V.

An active discharger operates as follows. The concentration of surfaces with even potentials at the pin point causes high voltage, which ionizes the ambient air; positive charges combine at the pin point with negative charges produced by the generator, and the remaining negative charges are removed by the air flow. This discharger creates strong radio interference, so it is turned /166 on only before landing or before performing loading-unloading operations.

The sensitive element of the discharger is a special device with stator and rotor plates. The stator plate is mounted on the helicopter fuselage in a teflon case. The rotor plate is butterfly shaped and is driven by an electric motor. It periodically shields the stator plate from the external electric field. The output signal frequency taken from the stator plate is 40 Hz when the speed is 20 rps. When the rotor shields the stator, the compact switch located in the axis of rotation periodically connects the stator plate to the helicopter fuselage. The sensitive element output voltage is thus converted from sinusoidal to half-sinusoidal, and the amplitude and the voltage sign correspond to the magnitude and polarity of the static charge. The sensitive element signal flows through a solid-state amplifier and is used to control the high voltage

source, which supplies the corona discharger mounted at least 15 cm beyond the helicopter tail boom. The high voltage source is obtained by the connection to the 28 V direct current on-board net and draws a current of 2 A, which is supplied to the transformer coupled transistor multivibrator. The two transfomer output windings are connected to the base-emitter circuit of two medium-power intermediate transistors, into the common collector circuit of which is connected the primary winding of the high-voltage output transformer. The mean value of the output voltage is 25 V, the current 1 mA. Two signals are fed into the high voltage source control circuit. One signal controls high voltage on and off, and the second sets its polarity. The high voltage part of the source, submerged in oil, consists of a voltage quadrupler, a voltage divider and a two-pole relay, which changes polarity at the output. The dimensions of the discharger are 204 x 230 x 306 mm.

Chapter 6

Some Special Features of Testing Aviation Materiel Intended for Use Under Complex Natural-Climatic Conditions /167

A large amount of information is needed to design and test items which are to operate reliably in different geographical and climatic regions. Obviously, an item designed without regard to the conditions under which it is to be used will be unreliable, or its cost will be unjustifiably great.

Before designing, one must know precisely under what conditions the item will be stored and operated (in precisely which climatic region, or in any regions), and have detailed data on the climatic, geomorphological (surface, topography, soil types), biological (microorganisms, flora, fauna) and other features of the region of operation, as well as on the storage conditions (in a room, under a canopy, under a cover, or outdoors).

If the item is intended for use under different climatic and geographical conditions, the most demanding combination of unfavorable factors which may affect it jointly during operation and storage must be selected. The role of the state and branch standards establishing the item's specifications for operation in different natural-climatic conditions grows in this case. These standards must be expanded systematically and made more precise, and must contain the latest information on the action of the natural conditions in different regions on /168 the items.

When designing an item, one should have an idea of the processes which cause the failure of its individual components. The changes in the physico-mechanical properties of materials, parts and their combinations with the action of temperature, humidity, and so forth have been studied far from sufficiently at present. The detailed investigation of the failure processes of standard structural elements under the effect of individual factors of the natural-climatic conditions, as well as their combinations, is one of the primary tasks demanding urgent accomplishment. An analysis of the results of the operation of similar items under the same natural conditions is very important, because such information is not available at present. Naturally, technical progress requires the increasingly frequent use of essentially new materials and structures; however, there usually is continuity. Analysis and prediction of measures to

increase the reliability of the item being designed are possible when there is effectively incoming data on the failures of similar equipment. Precise, objective and effectively incoming information on the reliability of operation, characteristic failures, and the operating properties of mass-produced items used in different regions is especially important for this reason. It is extremely important when analyzing this information not to permit, however infrequently it is done, the loss of personal responsibility for the data coming in from different regions. This sharply reduces the value of the information and makes it impossible henceforth to examine failures in connection with the external factors causing them.

A system of tests to which the produced item should be subjected must be developed simultaneously with the design (in no case later). The existing standards (norms) may give only the general direction of this work. Methods and equipment for conducting all types of tests should be developed in conformity with storage and operating conditions. The effort involved in this work is completely commensurate with the expenditures for designing and building a new model so they should be carried out simultaneously. The factors, the action of which is critical for item reliability, should be determined first, the /169 sequence of their action during testing assigned, and the possible combinations of the factors established. The number of models of the item to be tested (to obtain sufficiently reliable results), the volume of tests, and the time allowed for conducting them are determined at the same time. The most complex is the drawing up of the testing program for the combined action of various factors, which requires a sufficiently profound knowledge of the operating conditions and the damaging action mechanism of individual factors and their combinations. Drawing up a testing program for items intended for use in many regions of the earth is especially complicated.

When modifying mass-produced models for use under different natural-climatic conditions, the volume of tests may be reduced considerably if reliable information is available on the operating features and characteristic failures of items of the preceding types under these conditions.

Special Features of Testing

The purpose of testing is to provide an imitation of the real external factors by using reproduction testing methods.

Tests are conducted in laboratory, as well as in field, conditions. Most important here is to establish the optimum ratio between the volumes of laboratory and field tests. The positive side of laboratory tests is their comparatively low cost, the possibility of conducting them in a short time, independence from the season and meterological conditions, convenience of making observations, and high quality of measurements. The development of accelerated testing methods, which give results in a short time which would require a long time under natural conditions, is very promising in view of the special importance of the time factor when creating new equipment. An obstacle to the creation of these methods is the lack of knowledge on the action mechanisms of individual factors, and especially their combinations, on materials, structures, and various types of equipment. This especially concerns /170 essentially new structures.

The incompleteness of information requires supplementing laboratory tests with tests under field (range) conditions. Despite all the care of laboratory tests, completely unexpected (and very important) results often are obtained, which require the introduction of radical changes into the structure or specifications of the materials and completing articles being used. Unfortunately, conducting these tests requires great expenditures of time and means, and involves great difficulties in organizing communications, taking measurements, and ensuring the stability of results.

It is known, for example, that the years with the lowest winter temperatures are repeated at intervals of many years. Another example illustrating the difficulty of organizing field testing is the 11-year cycle of solar activity, during which it varies quite widely. Therefore, years are required to obtain reliable results from field tests. Nevertheless, field tests under real conditions at the current level of knowledge and testing technology are necessary.

When conducting laboratory tests, consideration of the frequency of the action of natural factors and the correct determination of the proportion of time of their action during the equipment's service life are very important. For this, the statistical distribution of the time of action of individual factors, as well as their combinations, must be arranged first of all according to data of many years in the earth's different natural-climatic zones.

Reproducing the Conditions Characteristic of Natural-Climatic Zones

Determining the required degree of imitation of external conditions is a complicated problem when drawing up a laboratory testing program. Two approaches are possible here.

An exact reproduction of external factors is the ideal from the point of view of reliability of obtained results. However, this is difficult to accomplish for technical reasons. In addition, an exact reproduction presupposes an identical time scale factor; that is, the duration of the tests should be equal to the /171 service life of the item. The testing time becomes unacceptable given a sufficiently great service life of the item being tested. Moreover, the distribution of the external condition factors in time is statistical in nature. Therefore, the question unavoidably arises of precisely which combination of factors should be imitated during testing. In addition, the testing cycle is prolonged considerably due to the need to imitate the natural change in the factors with respect to season.

Thus, an exact reproduction of external storage and operating conditions under laboratory conditions is technically complicated, uneconomical, and leads to a great expenditure of time on testing.

Knowing the action mechanism of the damaging factors on the components of the items being tested, an attempt can be made to create "synthetic" external conditions in the laboratory. This means that the item being tested should undergo the same damage as under the action of real storage and operating conditions, the destructive processes being forced, which ensures a sharp reduction in testing times. Unfortunately, the insufficient level of knowledge on the destruction processes of the materials, components, and systems of items (articles) when damaging factors of the external conditions are acting makes it impossible to use this approach fully as a practical matter. Even the simplest processes of mechanical destruction under the action of vibrations have been extremely poorly investigated. Therefore, it is very important to study carefully the kinetics of destruction and their link with destructive factors (temperature, chemical, biological, electrical and mechanical, as well as their combinations). Only then may the "specific weights" of the action of various destructive factors and their combinations be reliably established for each type of materiel and equipment, as well as for individual types of materials

and coatings.

Another difficulty when creating accelerated testing methods is the insufficient development of the "calculated risk" principle, which must be used in the analysis and selection of damaging factors as the basis for testing. The point /172
is that the simple use of the extreme values of each factor without regard for this principle leads to the unjustified complication of equipment and to expenses. Thus, we can use a calculation for items based on temperatures observed once in a century, which obviously is unreasonable. The "calculated risk" criteria should be different for long storage conditions and for operating conditions.

Thus, the numerical values of the damaging factors of natural conditions should represent not just their extreme values, but a modification of these by applying the "calculated risk" principle. A desirable modification permits obtaining more inexpensive equipment and materiel, which will function reliably with a sufficiently high probability during the entire time of operation, and will be stored for the necessary amount of time without going out of order.

The modification should be based on an analysis of data obtained earlier during laboratory and field tests, information on failures during operation and storage, and the results of scientific research on the destructive action of various factors of the natural-climatic conditions, and primarily their combinations.

In addition to those indicated, a complex problem is the establishment of a one-to-one relationship (correlation) between the results of laboratory tests and data obtained during field tests and the results obtained during operation.

Meanwhile, the knowledge of this relationship is vitally necessary to establish the practical value and the specific weight of each type of test. This field still needs vast research work so that the results of laboratory and field tests may be used reliably in evaluating designed and modified items.

Thus, the basic problems at present are the following:

obtaining comprehensive information on storage and operating conditions for all types of equipment in various regions of the earth;

obtaining objective and effective information on the operational data and /173
characteristic failures of each type of equipment under different storage and

operating conditions;

an effective analysis and generalization of all information and its presentation in a form convenient for processing and storage in an electronic computer, as well as for practical use;

studying the interrelationships between the destructive factors when they act jointly in different combinations;

creating probability methods of presenting the primary damaging factors in accordance with the "calculated risk" principle;

developing a concept of the "specific weight" of each factor and their combinations;

developing methods of correlating the results of laboratory and field (range) tests, as well as operational data;

developing methods of correlating the newly-created testing methods with the methods used previously;

developing methods of correlating tests on a real time scale and accelerated tests;

developing more perfect methods of reproducing natural-climatic conditions;

studying the action of the destructive factors of natural-climatic conditions in order to reproduce it adequately in accelerated tests;

creating a standard terminology and a coding system to facilitate the compilation and processing of information on failures occurring during the storage and operation of equipment.

REFERENCES

Aleksandrov, V. G., et al., Tekhnicheskaya ekspluatatsiya aviatsionnoy tekhniki [Technical Operation of Aviation Materiel], Voyenizdat, Moscow, 1967.

Vedrov, V. S., Tayts, M. A., Letnyye ispytaniya samoletov [Aircraft Flight Tests], Oborongiz, Moscow, 1951.

Vul'f, B. K., Romadin, K. P., Aviatsionnoye materialovedeniye [Aviation Materials Science], "Mashinostroyeniye" Press, Moscow, 1967.

Gubkov, A. I., Leshakov, P. S., Raykov, L. G., Vneshniye nagruzki i prochnost' letatel'nykh apparatov [External Loads and Aircraft Strength], Oborongiz, Moscow, 1963.

Zrelov, V. N., Piskunov, V. A., Reaktivnyye dvigateli i topliva [Jet Engines and Fuels], "Mashinostroyeniye" Press, Moscow, 1968.

Konychev, V. I., Amortizatory samoletnogo oborudovaniya [Aircraft Equipment Shock Absorbers], Oborongiz, Moscow, 1956.

Losev, I. A., Troyanovskaya, Ye. B., et al., Nemetallicheskiye materialy i ikh primeneniye v samoletostroyenii [Non-metallic Materials and Their Use in Aircraft Construction], Oborongiz, Moscow, 1958.

Pavlenko, V. F., Samolety vertikal'nogo vzleta i posadki [Vertical Take-off and Landing Aircraft], Voyenizdat, Moscow, 1966.

Pugachev, A. I., et al., Tekhnicheskaya ekspluatatsiya letatel'nykh apparatov [Technical Operation of Aircraft], "Transport" Press, Moscow, 1967.

Tenishev, R. Kh., et al., Protivoobledenitel'nyye sistemy letatel'nykh apparatov [Aircraft Anti-Icing Systems], "Mashinostroyeniye" Press, Moscow, 1967.

Trunov, O. K., Obledeneniye samoletov i sredstva bor'by s nim [Icing of Aircraft and Ways of Combating It], "Mashinostroyeniye" Press, Moscow, 1965.

Teslenko, A. I., Obledeneniye aviatsionnykh gazoturbinnykh dvigateley [Icing of Aircraft Gas-Turbine Engines], Voyenizdat, Moscow, 1961.

Chestnov, A. V., Letnaya ekspluatatsiya samoleta [Aircraft Flight Operation], Voyenizdat, Moscow, 1962.

Shchedrov, K. P., Gakman, E. L., Zharostoykiye materialy [Heat-Resistant Materials], "Mashinostroyeniye" Press, Moscow, 1965.

Journals:

Aviatsiya i kosmonavtika, No. 5, 1964; No. 4, 1969.

Voyennaya aviatsiya i raketnaya tekhnika, No. 6, 1966.

Vestnik PVO, No. 7, 1958; No. 6 and 7, 1964; No. 8, 1965; No. 2 and 7, 1966.

Vestnik Vosdushnogo Flota, No. 4 and 11, 1952; No. 1, 1953; No. 7, 1954; No. 12, 1958.

Aircraft Engineering, No. 5, 1965.

Aeroplane, No. 1709, 1944; No. 2948, 1968.

Aero Digest, No. 1, 1948; No. 1, 1950.

Aviation Week, No. 1, 1948, No. 23, 1967.

Aeroplane Safety, No. 8 and 12, 1964; No. 7 and 8, 1966.

Canadian Aeronautics Space Journal, No. 9, 1964, No. 7, 1969.

Engineering, No. 4439, 1951; No. 5166, 1965.

Mechanical Engineering, VIII, Vol. 70, 1948.

Petroleum Times, No. 1761, 1965.

Popular Science, No. 4, 1944.

Royal Aeronautics Society, No. 659, 1965.

SAE preprints, No. 683D, 1963; No. 922A, 1964.

SAE Journal, No. 8, 1966.

Western Flying, XI, 1944.

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